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LAKEVIEW TGS CHIMNEY 3 ASSESSMENT OF FLEXIBLE EPOXY AND POLYURETHANE INJECTION RESINS FOR USE IN REPAIRING CRACKS

Report No. 90-71-K

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ABSTRACT

A study was undertaken to evaluate flexible epoxy and polyurethane grouts for use in repairing cracks in the concrete of Lakeview TGS Chimney 3 (Units 5 & 6). Tests were carried out on nine materials to determine the viscosity, the temperature rise and gel time, the effect of exposure conditions on change in physical properties, and the flow characteristics of the materials when injected into simulated cracks. The performance of the epoxies and polyurethanes was influenced by crack width, ambient temperature, pot life, and viscosity of the material. The physical characteristics and performance results of the materials tested are outlined in this report. The tensile elongation properties of flexible epoxies and polyurethanes are limited, especially in a large area such as a crack. The polymer cannot be elongated to the same degree as that observed when testing small (i.e., 50 mm) diameter cores.

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LAKEVIEW TGS CHIMNEY 3 ASSESSMENT OF FLEXIBLE EPOXY AND POLYURETHANE INJECTION RESINS FOR USE IN REPAIRING CRACKS

1.0 INTRODUCTION

At the request of Civil Design, a limited study was carried out to assess the ability of flexible epoxy and polyurethane resins, having different viscosities, to penetrate cracks in concrete. This work helped define the parameters of using flexible materials to repair and bridge cracks in Lakeview TGS Chimney 3 (Units 5 & 6).

2.0 LITERATURE REVIEW

Materials suitable for the repair of cracks in concrete structures vary widely, but are generally based on some form of a binding agent that when mixed will flow easily into cracks and then will harden to form a solid mass. Preferably, the hardened grout will bond to the crack surfaces to form a support bearing filler. In general, these requirements can be met with one of two types of materials: a hydraulic cement or a chemical grout. This study is concerned only with chemical grout materials, specifically grouts based on synthetic organic polymers.

In previous work for the repair of Lakeview TGS Chimney 2, rigid epoxy grouts of varying viscosities were studied/1/. Since re-cracking of the chimney occurred through the repaired crack, it was thought that more flexible materials should be studied to determine their ability to penetrate cracks and accommodate some movement.

Based on information and opinions from technical literature and manufacturers, two types of organic materials were identified: flexible epoxy resins and flexible polyurethane resins.

3.0 FACTORS AFFECTING SELECTION OF GROUTS FOR TESTING

Repair of the Lakeview TGS Chimney 3 requires pressure injection of a grout into the crack where it must :

- penetrate the crack as extensively as possible,
- wet the surface of the cracks,
- gel or otherwise cease to flow when injection is completed to prevent possible leakage through the back of the crack where it is not possible to seal it,
- have a gel time long enough to ensure that the grout travels to the farthest point in the crack,
- harden to form a flexible mass that can accommodate reasonable movement and that remains in place for the life of the repair, and
- be durable.

Polyurethane materials are available in two types: one- and two-component systems. Within each type there are products with different characteristics, which are outlined below.

ONE-COMPONENT POLYURETHANES	TWO-COMPONENT POLYURETHANES
Rigid Hydrophobic Foams stable, but no flexibility main use - seepage control, especially in soils and underground where lack of flexibility is not a disadvantage	Flexible Hydrophobic Gel stable, flexible, elastomers good strength and penetrability possible use for structural repair in concrete
Flexible Hydrophobic Foams maintain volume but have good flexibility contain some open cells so they perform best when cured under pressure most effective for leaking active cracks	Water-Compatible Hydrophobic Gel displaces standing (but not running) water in cracks without reacting with it good adhesion to concrete remains flexible not affected by wet/dry cycles
Hydrophillic Foams of Gels continue to absorb water after curing best used in confined areas where expansion tightens the seal not advised for situations where there will be wet/dry cycles	Hydrophillic Elastomer for cure under dry conditions only contact with water after curing will swell the product, forming a seal can be used as preventive maintenance, or for repair of a wet crack that has been allowed to dry out Hydrophobic Foam forms hard and tough, mainly closed cell foam expands 1:3 good adhesion to substrate, so high strength

ONE-COMPONENT POLYURETHANES	TWO-COMPONENT POLYURETHANES
Rigid Hydrophobic Foams	Flexible Hydrophobic Gel
TACSS20 Deci 16 MME Universal Mountaingrout Resicast GH67/Fox-o-cat 710 Rocagil PU	MME Polycast Std MME Polycast LV Flexifix Resicast GH 40 Resicast GH 65
Flexible Hydrophobic Foams	Water-Compatible Hydrophobic Gel
Flex 44 Flexigel Mountaingrout Flex Resicast GH72	MME Polycast WTR ELMF
Hydrophillic Foams or Gels	Hydrophillic Elastomer
CR-grouts (3M) Scotchseal (3M) Superseal AV-grouts (3M, Denys) MME Multi-gel Resicast GH77 Resicast GH80	MME Polycast Exp.
	Hydrophobic Foams
	Rock Grip Roklok-LV3, LV4 Bevedan/Bevedol

The single-component urethanes are used mainly where water seepage is a problem and were not considered in these tests. Of the two-component systems available, two flexible water compatible hydrophobic gels, MME Polycast WTR and ELMF, one flexible, hydrophobic foam, LV3, and one rigid hydrophobic foam, LV4, were selected for testing.

Epoxies are two-component systems comprising an epoxy resin and a hardener, which react to form the cured resin. Epoxies are generally hard and brittle, but they can be formulated to be flexible with some elongation potential. Typical products available are listed below:

TRADE NAMES OF COMMERCIAL EPOXY GROUTS

RIGID	FLEXIBLE
AV530 Capweld 333 Capweld 524 Capweld 624 Concressive 1077 Concressive 1380 Denepox 40 Nitobond ULV Sikadur 35 Sikadur 52 Sikadur Injection Gel	Capweld F1 Capweld F2 Capweld F3 Sikadur 8132

Four flexible epoxies (Capweld F1, F2, F3 and Sikadur 8132) and one rigid epoxy (Capweld 333) were selected for testing.

The general characteristics of the materials tested are given in Table 1.

4.0 LABORATORY TESTS

4.1 Test Variables

Due to the limitations of time and budget, it was not possible to study all factors affecting the injection process. The variables considered for this work (Table 2) and the results obtained are described as follows:

4.1.1 Crack Width

To determine the minimum and maximum crack width that can be grouted, and to study flow of the grouts in cracks of different widths, tests were designed to simulate a range of crack widths from approximately 0.005" to 0.125"/2/. The specimens used consisted of plexiglas/concrete and concrete/concrete models and are described in detail below.

4.1.2 Viscosity of Injection Resins

To obtain a representative range of viscosities, nine injection resins were tested. The viscosity of the materials when tested using a Brookfield Viscometer ranged from 70 to 2 300 cps for the urethane grouts and 2 000 to 16 000 cps for the epoxy grouts (Figure 1).

4.1.3 Tack and Hard Times

The tack and hard times of the various materials were determined at 20°C using a dry time recorder. The material thickness used to determine these times was 0.016". The results of these tests are shown in Figure 2. The tack and hard times of the polyurethane resins ranged from 0.3 to 1.9 hours and 1.1 to 3.5 hours, respectively. For the epoxies, the tack and hard times varied from 2.9 to 9.25 hours and 7.0 to greater than 11.0 hours, respectively.

4.1.4 Temperature Rise and Gel Time

The temperature rise and gel time of the materials tested were determined using 100 mL samples. The results are summarized in Figure 3 and Table 3. The maximum temperature rise of the polyurethanes varied from 3° to 106°C. The gel times were generally influenced by the rate of reaction (i.e., temperature development) and they varied from 2 to 50 minutes. The temperature rise of the epoxies in general was greater than that of the polyurethane grouts, varying between 47° and 142°C. The gel times, however, were not as short for epoxies as for the polyurethane grouts and ranged from 33 to 84 minutes (see Table 3). The longer gel times of the epoxies provide better assurance of crack penetration during injection.

4.1.5 Compressive Strength and Load Deformation Characteristics

The compressive strength and load deformation characteristics of the materials were determined in accordance with the American Society for Testing and Materials (ASTM) C 109. The materials were tested at three temperatures, 23°, 40°, and -10°C, to ascertain the effect of ambient temperature on the change in compressive strength and load deformation characteristics (i.e., the ability of the material to deform or retain its initial modulus with changing temperature).

The results are outlined in Table 4 and Figures 4 to 8. The compressive strength of the epoxies and polyurethanes ranged between 31.2 and 62.0 MPa for the rigid materials and 0.3 and 2.1 MPa for the flexible materials (see Table 4). The ultimate compressive strength and load deformation characteristics of some of the materials were significantly influenced by the exposure temperatures. As temperature increased, strength reduced and deformation increased. The opposite effects were generally noted for the specimens tested at -10°C (i.e., increased strength and reduced deformation).

4.1.6 Effect of Exposure Temperature on Shore A and D Durometer Hardness and Weight Change

To determine the effect of changes in ambient temperature on the performance of the cured materials, specimens were initially made at 23°C and subsequently stored at four temperatures, 23°, 50,° 100° and -10°C. Shore A and D durometer hardness and changes in weight were then measured at the test temperatures. The results are summarized in Table 5 and Appendix A.

As the exposure temperature increased above 23°C, the durometer hardness generally decreased. At 50° and 100°C, the Shore A and D hardness varied from 16% to 95% and 26% to 81%, respectively when compared to the 23°C measurements. One material (ELMF) melted at the 100°C exposure temperature.

At -10°C, changes in Shore A and D hardness ranged from 66% to 225%, with most materials showing an increase in hardness. The ELMF and WTR polyurethane showed no increase in hardness as a result of exposure to the lower temperature.

The materials exposed to 23°, 50°, and -10°C did not show a significant change in weight (i.e., less than 0.5%). However, the WTR polyurethane did show a 3.2% reduction in weight and evidence of shrinkage. Exposed to 100°C, the materials had a variable performance. The rigid epoxies and polyurethane (material 333, 8132, LV4) had less than 1.0% weight loss. The flexible materials were more adversely affected by the higher temperature. The epoxies reduced in weight by 2.5% to 3.0%. The ELMF polyurethane melted and the WTR polyurethane shrank significantly resulting in a 25% weight loss.

4.2 Slab Tests

The slab tests were designed primarily to study the flow characteristics of the epoxies and polyurethanes. Temperature was maintained at 20°C. The materials were injected into cracks of various widths between plexiglas/concrete and concrete/concrete models. Two methods of injecting the materials were used: hand-operated caulking guns and a polyurethane injection machine that mixes the polyurethane components at the nozzle. Injection pressures varied from less than 20 to 200 psi, depending on the viscosity of the material and the width of the crack.

To simulate cracks in the laboratory, concrete slabs 24" x 9" to 18" x 4" thick were cast. After the slabs were cured, one face was sandblasted, and then the specimens were assembled as follows:

4.2.1 Plexiglas/Concrete and Concrete/Concrete Models

One concrete slab was placed vertically, and a plexiglas plate was placed directly against the sandblasted face to simulate small cracks. The assembly was held together with 'C' clamps (Figure 9). The plexiglas was of sufficient thickness to prevent deforming due to pressure exerted during injection. The same process was repeated for other models; however, shims were installed on the concrete prior to placing the plexiglas to simulate wider cracks.

Once the assembly was complete, one edge of the simulated crack was prepared for injection. An injection port was installed at the base of each model and at four inch centres thereafter along the edge. The base and side of the slab at the simulated crack were then sealed with an epoxy mortar, leaving the back and top of the crack open.

The same procedure was followed for assembling concrete/concrete models, using two concrete slabs. As noted later in the tables, for some of the models, the back of the crack was left open while for others it was sealed.

4.2.2 Epoxy and Polyurethane Injection

As soon as all cracks were prepared and the surfaces sealed, pressure grouting commenced (Figures 10 to 12). The test consisted of grouting into the lowest port (Port 1) until material appeared at the next port (Port 2), or until it reached the backside of the open-ended crack, or until it was apparent that the flow would not reach either point. The time of injection was recorded for each port, and the flow patterns of the epoxy and polyurethane were identified. The injection inlet was then connected to the next port, and the procedure continued until the injection was complete. Throughout the grouting operation, appropriate data were recorded to aid in later analysis of all operations (Table 6). The results of this work are presented in Appendix B (plexiglas/concrete models) and Appendix C (concrete/concrete models). The following observations were made:

a) The vertical flow of the epoxy and polyurethane materials generally tended to be greater than the horizontal flow, except for the low viscosity polyurethanes (200 cps and less). The flow patterns were generally the same as those observed in the previous study (i.e., flow patterns within a crack range from semi-circular in one extreme to semi-elliptical in the other, major axis along crack surface - see Figure 11).

b) Gravity had a great effect on flow when using the low and medium viscosity materials, especially in wide cracks. However, for the high viscosity materials, minimal flow was observed except when pressure was applied.

c) The variance in flow patterns was mainly a result of the crack width variation, and viscosity of the material. Therefore, to ensure maximum crack penetration, the spacing of ports should be a minimum of the thickness of the wall being injected.

d) The low viscosity materials (100 to 2 800 cps) were relatively easy to inject at pressures between 20 to 80 psi, regardless of crack width. They were generally effective in sealing narrow cracks; however, where cracks were not sealed from the backside, there was a significant loss of material. This loss increased significantly with an increase in crack width.

e) For the intermediate to high viscosity materials (8 000 to 16 000 cps), significantly higher injection pressures were required (90 to 200 psi) to fill the models having small crack widths. For the same materials injected into wide cracks (0.125"), injection pressures were much lower. During injection, some material leaked out of the back of the crack; however, at the completion of injection, minimal material leaked out with no reduction in level of the material in the crack.

f) Overall, it was observed that as the radial penetration increased, so did the injection pressure in order to maintain the injection rate.

g) Regardless of the material used, generally all models were completely filled during injection.

h) Most materials had sufficient pot life to ensure complete filling of the models; however, three polyurethanes (LV3, LV4, ELMF) had a relatively short pot life and could pose problems in the field where long injection times are required.

4.2.3 Further Measurements and Testing of Models

After the material had fully cured, the plexiglas/concrete models were dismantled. The thickness of the epoxy and polyurethane was measured at several locations. Information is provided under notes in the tables in Appendix B.

The concrete/concrete slabs were cored at several locations to determine the depth of penetration and the material thickness (Table 7). A few selected cores were then prepared and tested in direct tension to determine the bond strength of the epoxy and polyurethane to the concrete and to measure the tensile elongation of the materials. Tests were carried out at 40°, 23° and -10°C to ascertain the effect of temperature on the performance of the materials. The test sections cored from the concrete/concrete models had tensile bond strengths ranging from 0 to 2.4 MPa (Table 7). Failure mode varied from adhesive to concrete failures. The tensile elongation of the materials ranged from 0% for the rigid materials to 208% for the flexible materials. The following observations were made:

a) The flexible polyurethanes, (ELMF and Polycast WTR, Figures 13 and 14) generally retained their ability to elongate more with changing temperatures when compared with the flexible epoxies (F1 and F3). However, the tensile bond strength to concrete was significantly lower for the urethanes (0 to 0.37 MPa) compared to the epoxies (0.5 to 2.42 MPa).

b) At 23°C, the flexible polyurethanes elongate 0% to 102%. At -10°C, the tensile elongation generally increased from 17% to 208%, probably as a result of the increase in bond to the concrete due to the subfreezing temperature. The materials also provided better elongation at 40°C when compared with the 23°C results. This improvement might

be attributed to the lower modulus of elasticity , as the bond strength to concrete was not improved.

c) The LV3 polyurethane also produced more elongation than that of the epoxy; however, the elongation significantly reduced at the lower temperature and increased at the higher temperature, when compared with the 23°C results.

d) Although the flexible polyurethanes provided good elongation characteristics, generally their bond to concrete was low and their stability at high temperatures was questionable. Further testing is required to better understand the stability and performance characteristics of these materials when exposed to higher temperatures.

e) LV4, 8132/3/ and 333 are rigid materials and were generally unable to accommodate movement even at the different test temperatures (Figure 15). The LV4 material performed very poorly providing little to no adhesion. The other two materials had high tensile bond strength to concrete, with all failures occurring in the concrete.

f) The flexible epoxies (F1 and F3) elongated 7% to 12% at 23°C with tensile bond strengths ranging between 0.7 and 1.19 MPa. When exposed to -10°C, the ability of the epoxies to accommodate movement was significantly reduced (elongation 0.4% to 0.6%), indicating that the modulus of elasticity had increased (Figures 16 and 17). The tensile bond strengths also increased at the lower temperatures (1.8 to 2.42 MPa), resulting in ultimate failure within the concrete. At 40°C, the tensile bond strengths on average were approximately 20% lower than the 23°C results. The ability of the epoxies to accommodate movement at the higher temperatures was similar to the results at 23°C.

The concrete-to-concrete models were further dismantled to provide additional observations on the performance of each material. These results are summarized in Table 8.

5.0 DISCUSSION

5.1 Crack Type and Nature of the Interface

Where cracks are dormant, good results can usually be obtained with rigid epoxy systems, which are usually stronger than the concrete itself. However, if the crack is active and is repaired using these resins, it is likely to occur again (usually elsewhere in the structure), because the strength of the repair material merely transfers the stresses that caused the original crack.

For an active crack, there are two choices of action: to structurally repair the crack and be prepared to repair again in the future at an unforeseeable new location, or to seal the crack if the remaining structural strength is sufficient. If the latter is considered, then the grout of choice would be a flexible grout that will adhere to the concrete surfaces and allow some movement,

but that has lower cohesive strength than the strength of the concrete. This may also simplify future inspections, since the sealed crack remains the weakest part of the structure.

The condition of the crack surfaces with which the grout will interface can drastically affect the end result of the grouting operation. This is especially so in the case of a structural repair, where the interface bond is the major factor in a successful grouting operation. Anything that contaminates the surfaces interferes with this bond, and will greatly reduce the effectiveness of the repair.

Any grout that fills the void and provides a surface seal against the ingress of water (which could continue to propagate the crack through freezing and thawing) or other harmful constituents will at least slow down the rate of deterioration.

For repair of this Lakeview Chimney, a grout that will accommodate reasonable movement will probably provide more effective results.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Overall, the performance of the epoxy and polyurethane grouts is influenced by crack width, ambient temperature, pot life, and viscosity of material. The following general conclusions can be made:

a) All the epoxies when used at proper viscosity provided adequate working time to ensure penetration of a given crack size. Polyurethanes which generally have shorter working times, could pose problems with injection if proper equipment and procedures are not followed.

b) The compressive strength of the flexible materials was low, ranging from 0.3 to 2.1 MPa at 23°C. The polyurethanes developed lower strengths; however, no significant change in strength was observed at the different test temperatures. The epoxies exposed to 40°C reduced and those exposed to -10°C increased significantly in strength. The strength of the rigid materials varied with changes in temperature, increasing in strength at low temperatures and significantly reducing in strength at high temperatures.

c) For the flexible materials, the Shore A and D hardness (i.e., change in modulus) generally decreased at the higher exposure temperatures and increased at the lower temperatures when compared to the 23°C test results. The WTR and ELMF polyurethanes showed no increase in hardness when exposed to the lower temperature. However, the same two materials were adversely affected when exposed to 100°C showing significant shrinkage and changes in hardness and weight. The ELMF material melted at the 100°C test temperature.

d) With the exception of WTR and ELMF, all other materials had minor changes in weight and showed no significant shrinkage regardless of the exposure temperature.

e) The rigid materials were least affected by temperature change, except at 100°C exposure where the hardness generally reduced significantly.

f) The low viscosity materials were relatively easy to inject in the simulated cracks; however, significant losses of material occurred where cracks were open on the backside. The intermediate to high viscosity materials required significantly higher injection pressures to fill small cracks and much lower injection pressures to fill wide cracks. Although some material leaked out the back of an open-ended crack during injection, generally no reduction of the level of material in the crack occurred after injection.

g) The rigid epoxy materials generally provided significantly higher tensile bond strengths than the polyurethane grouts; however, neither material could accommodate any movement.

h) The flexible epoxy materials provided good elongation at 23°C and 40°C, although the tensile bond strengths were much lower than those of the rigid materials. At -10°C the flexible epoxies could accommodate very little movement, although the tensile bond strength to concrete was high. The modulus of elasticity increases significantly at the lower temperatures. Further modification in the formulation of flexible epoxies would result in an improvement in the elongation of these materials at low temperature.

i) The flexible polyurethane grouts had overall better elongation characteristics than the epoxies; however, the tensile bond strength to concrete was low. These materials were also adversely affected when exposed to high temperatures (ELMF melted and Polycast WTR shrank 25%).

j) Based on the anticipated exposure conditions and as a result of a previous condition survey of the exterior surface of Lakeview Chimney 3 (Figure 18), the following recommendations are made:

   i) For the hairline cracks (0.01" or less), no benefit will be gained by using a flexible material. Therefore, a rigid, low viscosity epoxy (Capweld 333) that will penetrate the crack fully and provide adequate adhesion is recommended.

   ii) Where cracks are in excess of 0.01", a flexible epoxy able to penetrate the cracks and provide adequate adhesion (i.e., tensile bond strength of 1.0 MPa) should be used. The material within a crack should have the ability to elongate 10% to 20% under the given exposure conditions. Modified versions of Capweld F1, F2, F3 could meet this requirement.

iii) The contractor should provide adequate test results to ensure the materials used meet the above conditions.

7.0 RECOMMENDATIONS FOR FUTURE WORK

a) Further work should be carried out to increase understanding of and to design materials that can be used effectively over a large temperature range.

b) The presence of moisture within a crack should also be studied to assess the effect it has on the performance of materials.

c) Consideration should be given to working with manufacturers to develop a range of grouts for application under different conditions (i.e., temperature, moisture, etc.) to meet Ontario Hydro's needs.

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REFERENCES

1. Lakeview TGS Chimney 2: Assessment of Epoxy Injection Resins for Use in Repairing Cracks. Ontario Hydro Research Division, Report No. S88-34-K, September 1988.

2. Information provided by Civil Design for Lakeview TGS Chimney 3. The major crack area consists of the wider crack size.

3. The manufacturer claimed that this material was flexible; however, it was subsequently found not to be.

TABLE 1

GENERAL CHARACTERISTICS OF ORGANIC GROUTS

MATERIAL EPOXY	POLYURETHANE	Characteristics in Cured State	Viscosity/Temp (cps)/(°C)	Application (Dry/Wet) Active (a)/Passive(p) cracks	Hydrophobic or Hydrophillic
Capweld F1	-	Flexible	2300/23	dry/wet (a)	Hydrophobic
Capweld F2	-	Flexible	8000/23	dry/wet (a)	Hydrophobic
Capweld F3	-	Flexible	16000/23	dry/wet (a)	Hydrphobic
Capweld 333	-	Rigid	9200/23	dry/wet (p)	Hydrophobic
Sikadur 8132[1]	-	Flexible	2000/23	dry/wet (a)	Hydrophobic
-	Polycast WTR	Flexible	200/23	dry/wet (a)	Hydrophobic
-	LV4	Rigid	70/23	dry/wet (p)	Hydrophobic
-	LV3	Flexible	70/23	dry/wet (a)	Hydrophillic
-	ELMF	Flexible	-	dry/wet (a)	Hydrophobic

[1]Manufacturer claimed that the material was flexible; however, based on tests carried out, the material is rigid.

TABLE 2

TESTING OF ORGANIC GROUTS

Material	Dry Time Recorder (0.016": thickness) Tack Time	Hard Time	Temp Rise (°C) 100 mL	Gel Time 100 mL	Effect of Exposure Conditions on Shore A/D Hardness and Weight Temperature Conditions (°C) -10	23	50	100	Injection of Simulated Cracks Plexiglas to Conc.	Concrete to Conc.	Compressive Load Deformation Characteristics 23°C	-10°C	Tensile Strength and Elongation of Composite Specimens
F1	x	x	x	x	x	x	x	x	x	x	x	x	x
F2	x	x	x	x	x	x	x	x	x	x	-	-	x
F3	x	x	x	x	x	x	x	x	x	x	x	x	x
333	x	x	x	x	x	x	x	x	x	x	x	-	x
8132	x	x	x	x	x	x	x	x	x	x	x	x	x
Polycast WTR	x	x	x	x	x	x	x	x	x	x	x	x	x
LV4	x	x	x	x	x	x	x	x	x	x	x	x	x
LV3	x	x	x	x	x	x	x	x	x	x	-	-	x
ELMF	x	x	x	x	x	x	x	x	x	x	-	-	x

TABLE 3

MAXIMUM TEMPERATURE RISE AND GEL TIME OF ORGANIC GROUTS

MATERIAL	MAXIMUM TEMP RISE (°C)	GEL TIME (Min)
F1	51	33
F2	48	48
F3	47	51
333	142	84
8132	69	78
WTR	14	50
LV4	106	2
LV3	115	2
ELMF	3	44

TABLE 4

COMPRESSIVE STRENGTH AND DEFORMATION CHARACTERISTICS OF EPOXY AND POLYURETHANE GROUTS

MATERIAL/3/	COMPRESSIVE STRENGTH (MPa)/1/					
	23°C Deformation		40°C Deformation		-10°C Deformation	
	5%	25%	5%	25%	5%	25%
F1	1.6	4.9	0.3	1.1	13.4	17.6
F2	1.6	4.6	0.3	1.4	18.6	20.7
F3	2.1	4.9	0.3	1.7	14.4	18.6
333	62.0	-	36.5	-	64.7	-
8132	31.2	-	3.1	7.8	55.3	-
WTR	0.3	0.3	/2/	/2/	0.5	0.5
ELMF	0.3	0.3	/2/	/2/	0.5	0.5
LV4	42.3	45.2	14.3	-	62.5	-

/1/ Specimens initially cured for 14 days at 23°C. Specimens were then stored at the different curing temperature for a minimum of 3 days and then tested at the temperatures noted above.

/2/ No test carried out because material was unable to sustain any load.

/3/ It was not possible to make specimens for the LV3.

TABLE 5

EFFECTS OF EXPOSURE TEMPERATURE ON SHORE A/D DUROMETER HARDNESS

		Change in Durometer Hardness and Weight (% of 23°C Measurements) Age - 10 days					Change in Durometer Hardness and Weight (% of 23°C Measurements) Age - 10 days		
MATERIAL	TEST TEMP. (°C)	Shore A	Shore D	Weight	MATERIAL	TEST TEMP. (°C)	Shore A	Shore D	Weight
F1	23	100	100	100	WTR	23	100	/1/	100
	50	61	49	100		50	74	/1/	98.9
	100	49	34	98.2		100	81	/1/	85.5
	-10	114	162	100		-10	66	/1/	100
F2	23	100	100	100	LV3	23	100	100	100
	50	77	84	100.2		50	74	71	100
	100	59	48	98.6		100	68	57	99.8
	-10	130	225	100		-10	75	108	100
F3	23	100	100	100	LV4	23	100	100	100
	40	84	89	100		50	80	63	100
	100	67	48	98.6		100	80	62	99.6
	-10	127	193	100		-10	91	106	100
333	23	100	100	100	ELMF	23	100	100	100
	50	91	95	100		50	16	/1/	99.6
	100	75	38	99.6		100	Mat. Melted	/1/	Mat. Melted
	-10	101	108	100		-10	96	/1/	100
8132	23	100	100	100					
	40	93	93	99.8					
	100	61	26	99.0					
	-10	89	104	100					

/1/ Not possible to obtain Shore D durometer hardness measurements.

TABLE 6
SUMMARY OF NOTES TAKEN DURING INJECTION OF PLEXIGLAS/CONCRETE AND CONCRETE/CONCRETE MODELS

MATERIAL	VISCOSITY (cps)	SPECIMEN WIDTH (in)	MEASURED CRACK WIDTH (in)	AVERAGE CRACK WIDTH (in)	QUANTITY OF GROUT INJECTED (fl. oz.)	INJECTION PRESSURE (psi)	TOTAL INJECTION TIME (min)	QUANTITY OF GROUT LEAKING OUT BACK OF CRACK (fl. oz.)	REFER TO FIGURE	REMARKS
PLEXIGLAS/ CONCRETE MODELS										
F2	8,000	9	0.006-0.015	0.009	8.0	120-140	15.0	2.0	B1	Material easy to inject. Required high injection pressures. Epoxy filled crack. Minor leakage of epoxy through back of open crack during and after injection (i.e., 10%).
F3	16,000	9	0.11-00.14	0.120	23.0	20-30	12.0	2.0	B2	Material very easy to inject. Required very low pressures to inject. Epoxy filled crack. Minor leakage of epoxy through back of open crack during injection (i.e., 9%)
F3	16,000	18	0.125	0.125	45.0	90-145	19.0	5.0	B3	Material easy to inject. Required relatively high injection pressures. Epoxy filled crack. Minor leakage through back of open crack during injection (i.e., ~11%)
8132	2,000	18	0.005	0.005	13.0	140-150	7.0	4.0	B4	Material easy to inject. Required high injection pressures. Epoxy filled crack. However, after completion of injection material drained, out through back of crack leaving approximately 25% of crack empty.
8132	2,000	9	0.05-0.07	0.055	15.0	20	15.0	4.0	B5	Material very easy to inject. At completion of injection 80% of material leaked out of back of crack.
Polycast WTR	200	9	0.004-0.006	0.005	6.0	30-40	11.0	2.7	B6	Material very easy to inject. Required very low injection pressures. Polyurethane filled crack. Considerable amount of polyurethane leaked out back of crack during injection. Material drained out through back of crack after injection, leaving approximately 45% of the crack empty.
LV3	100	9	0.125	0.125	16.0	<20	1.5	Back of crack sealed	B7	Material very easy to inject. Material expended out through top of crack producing foam. Good connection between ports.
LV3	100	9	0.05	0.05	16.0	<20	3.0	16.0	B8	100% of polyurethane drained out of crack during injection.
ELMF	2,800	9	0.05	0.05	18.0	20-80	11.0	1.0-2.0	B9	Polyurethane easy to inject. Generally required low injection pressures. Approximately 11% of material leaked out back of crack during injection. Level of polyurethane in crack did not reduce after injection.
CONCRETE/ CONCRETE MODELS										

TABLE 6 - CONT'D
SUMMARY OF NOTES TAKEN DURING INJECTION OF PLEXIGLAS/CONCRETE AND CONCRETE/CONCRETE MODELS

MATERIAL	VISCOSITY (cps)	SPECIMEN WIDTH (in)	MEASURED CRACK WIDTH (in)	AVERAGE CRACK WIDTH (in)	QUANTITY OF GROUT INJECTED (fl. oz.)	INJECTION PRESSURE (psi)	TOTAL INJECTION TIME (min)	QUANTITY OF GROUT LEAKING OUT BACK OF CRACK (fl. oz.)	REFER TO FIGURE	REMARKS
F1	2,300	9	0.025-0.065	0.04	18.0	30-160	6.0	8.0		Material generally easy to inject. At the completion of injection approximately 45% of material leaked out of crack. Back of crack sealed and specimen re-injected the next day.
F3	16,000	18	0.12-0.20	0.150	65.0	100-120	17.5	17.0		Material generally easy to inject, although relatively high injection pressures were required. Approximately 17.0 fl. oz. of material leaked out of crack during injection. However, at the completion of injection no further leakage occurred.
333 (MV/HV)	9,200	9	0.04-0.1	0.065	23.0	20-30	4.25	Back of crack sealed.		Material easy to inject requiring low injection pressures. Good connection between ports.
8132	2,000	9	0.01-0.08	0.04	11.0	-	6.25	Back of crack sealed.		Material easy to inject. Good connection between ports.
8132	2,000	9	0.045-0.125	0.075	16.0	100-140		8.0		Material generally easy to inject, although high injection pressures were required. 50% of material leaked out of crack after injection. Back of specimen sealed and material re-injected.
Polycan WTR	200	9	0.02-0.05	0.035	8.0	-	5.0	Back of crack sealed.		Material easy to inject. Good connection between ports.
Polycan WTR	200	18	0.045-0.1	0.065	19.0	30-60	5.75	Back of crack sealed.		Material easy to inject. Good connection between ports.
ELMF	2,800	18	0.04-0.110	0.07	26.0	120-160	9.0	6.0		Material easy to inject; however, required high injection pressures. Approximately 23% of material leaked out during injection. Level of polyurethane in crack did not reduce after injection.
ELMF	2,800	9	0.04-0.1	0.07	11.0	140-200	4.25	4.0		Specimen very difficult to inject partially due to material starting to setup during injection. Level of material reduced by approximately 36% after injection. Top of specimen re-injected the next day.
LV4	100	9	0.05-0.09	0.075	11.5	<20	0.8	Back of crack sealed.		Material easy to inject. Good connection between ports.
LV3	100	18	0.1-0.175	0.150	55.0	<20	2.5	Back of crack sealed.		Material easy to inject. Good connection between ports.
LV3	100	9	0.03-0.075	0.055	30	<20	2.5	6.0		Material very easy to inject. Some leakage of material through back of crack. Material started to expand within 15 minutes of injection out through back and top of crack producing a foam.

TABLE 7
TENSILE ELONGATION AND BOND STRENGTH OF CORES REMOVED FROM SIMULATED CRACKS EXPOSED TO DIFFERENT TEMPERATURES

MATERIAL	CORE LOCATION	PORT SIDE	BACK SIDE	CONDITION OF BACK OF CRACK DURING INJECTION		MEASURED CRACK WIDTH (in)	TEST TEMP (°C)	TENSILE BOND STRENGTH /V (MPa)	TENSILE ELONGATION		FAILURE MODE	
				OPEN	CLOSED				mm	%	CONCRETE %	BOND %
Capweld F1/1/ (9" width)	Top	X				0.035-0.06	-10	2.34	0.01	0.9-1.0	100	-
	Middle	X				0.025-0.04	23	0.88	0.07	7.0-11.0	20	80
	Bottom	X		X		0.025-0.06	40	0.85	0.08	5.0-13.0	30	70
	Top		X			0.03-0.06	40	0.82	0.13	9.0-17.0	30	70
	Middle		X			0.025-0.04	23	0.70	0.08	8.0-13.0	20	80
	Bottom		X			0.04-0.065	-10	2.42	0	0	100	-
Capweld F3 (18" width)	Top	X				0.130-0.160	-10	2.22	0.02	0.4-0.6	100	-
	Middle	X				0.120-0.160	23	1.19	0.37	9.0-12.0	20	80
	Bottom	X		X		0.125-0.160	40	1.0	0.17	4.0-5.0	20	80
	Top		X			0.115-0.200	40	0.5	0.35	7.0-12.0	10	90
	Middle		X			0.130-0.150	23	1.09	0.34	9.0-10.0	20	80
	Bottom		X			0.150-0.175	10	1.80	0.01	0.2-0.3	100	-
Capweld 333 (9" width)	Top	X				0.75-0.100	-10	1.73	0	0	100	-
	Middle	X				0.045-0.075	23	1.26	0	0	100	-
	Bottom	X			X	0.04-0.075	40	1.25	0.01	0.5-0.9	100	-
	Top		X			0.05-0.08	40	1.61	0	0	100	-
	Middle		X			0.055-0.08	23	1.80	0	0	100	-
	Bottom		X			0.045-0.06	-10	1.39	0	0	100	-
8132/1/ (9" width)	Top	X		X		0.04-0.05	40	1.72	0.01	0.6-0.9	100	-
	Middle	X				0.02-0.06	23	2.16	0	0	100	-
	Bottom	X				0.05-0.08	-10	1.5	0.01	0.4-0.7	100	-
	Top		X			0.025-0.05	-10	1.91	0.4-0.7	0	100	-
	Middle		X			0.015-0.05	23	1.79	0	0	100	-
	Bottom		X			0.01-0.04	40	1.92	0 0.9-1.1	0.9-1.1	100	-
8132 (9" width)	Top	X				0.08-0.120	-10	2.4	0.01	0.3-0.4	100	-
	Middle	X				0.05-0.075	23	0.7	0	0	100	-
	Bottom	X			X	0.05-0.075	-10	2.12	0	0	100	-
	Top		X			0.08-0.115	40	1.9	0	0	100	-
	Middle		X			0.045-0.05	40	2.38	0	0	100	-
	Bottom		X			0.05-0.125	23	2.07	0	0	100	-
Polycast WTR/1/ (9" width)	Top	X				0.02-0.05	-10	0.36	1.06	83.0-208.0	10	90/2/
	Middle	X				0.025-0.045	23	0.155	0.65	56.0-102.0	-	100
	Bottom	X			X	0.02-0.04	40	0.13	0.5	50.0-98.0	1-	90
	Top		X			0.02-0.04	40	0.20	0.65	64.0-128.0	1-	90
	Middle		X			0.025-0.05	-10	0.35	1.18	94.0-185.0	30	70/2/
	Bottom		X			0.025-0.05	23	0	0	0	-	100

TABLE 7 - CONT'D
TENSILE ELONGATION AND BOND STRENGTH OF CORES REMOVED FROM SIMULATED CRACKS EXPOSED TO DIFFERENT TEMPERATURES

MATERIAL	CORE LOCATION	PORT SIDE	BACK SIDE	CONDITION OF BACK OF CRACK DURING INJECTION		MEASURED CRACK WIDTH (in)	TEST TEMP (°C)	TENSILE BOND STRENGTH /3/ (MPa)	TENSILE ELONGATION		FAILURE MODE	
				OPEN	CLOSED				mm	%	CONCRETE %	BOND %
Polyest WTR (18" width)	Top	X				0.05-0.8	40	0.19	.43	21.0-34.0	10	90
	Middle	X				0.075-0.100	23	0.155	0.48	19.0-25.0	-	100
	Bottom	X			X	0.05-0.075	40	0.015	0.76	20.0-60.0	1-	90
	Top		X			0.05-0.08	-10	0.22	0.66	32.0-52.0	30	70/2/
	Middle		X			0.045-0.06	23	0.155	0.40	26.0-35.0	-	100
	Bottom		X			0.05-0.09	-10	0.37	0.92	40.0-70.0	5	95
ELMF/1/ (9" width)	Top	X		X		0.04-0.07	-10	0.16	0.41	23.0-40.0	30	70
	Middle	X				0.06-0.09	23	0.16	0.12	5.0-8.0	10	90
	Bottom	X				0.075-0.100	40	0.23	0.18	7.0-9.0	10	90
	Top		X			0.05-0.085	40	0.23	0.24	11.0-19.0	10	90
	Middle		X			0.06-0.09	23	0.21	0.2	9.0-13.0	10	90
	Bottom		X			0.06-0.09	-10	0.23	0.39	17.0-26.0	10	90
ELMF (18" width)	Top	X				0.06-0.100	-10	0.22	0.33	13.0-22.0	20	80
	Middle	X				0.05-0.100	23	0.19	0.18	7.0-14.0	10	90
	Bottom	X		X		0.07-0.110	40	0.14	0.25	9.0-14.0	10	90
	Top		X			0.045-0.075	40	0.16	0.24	13.0-21.0	10	90
	Middle		X			0.04-0.06	23	0.17	0.11	7.0-11.0	10	90
	Bottom		X			0.04-0.075	-10	0.24	0.38	20.0-37.0	10	90
LV4 (9" width)	Top	X				0.06-0.09	-10	0.82	.04	1.7-2.6	10	90
	Middle	X				0.05-0.075	23	0	0	0	-	100
	Bottom	X			X	0.05-0.075	40	0	0	0	-	100
	Top		X			0.05-0.075	23	0.04	0	0	10	90
	Middle		X			0.05-0.075	40	0	0	0	-	100
	Bottom		X			0.05-0.075	-10	0	0	0	-	100
LV3/1/ (9" width)	Top	X				0.035-0.06	-10	1.53	0.02	1.0-2.0	40	60
	Middle	X				0.03-0.065	23	0.33	0.24	15.0-31.0	10	90
	Bottom	X			X	0.05-0.075	40	0.12	0.7	36.0-55.0	10	90
	Top		X			0.04-0.075	-10	0.49	0.16	8.0-16.0	10	90
	Middle		X			0.05-0.07	23	0.76	0.25	14.0-20.0	10	90
	Bottom		X			0.04-0.075	40	0.90	0.43	23.0-42.0	20	80
LV3 (18" width)	Top	X				0.010-0.140	40	0.89	0.30	8.0-12.0	20	80
	Middle	X				0.140-0.175	23	0.33	0.31	7.0-9.0	20	80
	Bottom	X				0.140-0.175	40	0.54	0.79	16.0-19.0	20	80
	Top		X		X	0.100-0.140	-10	0.41	0.27	7.0-8.0	40	60
	Middle		X			0.150-0.175	23	0.43	0.24	5.0-6.0	20	80
	Bottom		X			0.140-0.165	-10	0.49	0.16	8.0-16.0	40	60

/1/As a result of a request from Civil Design to sandblast the concrete surfaces, it was not possible to maintain a crack width of 0.005".

/2/Cohesive failures

/3/All models after injection were cured for a minimum of 4 days at 23°C prior to coring and an additional 10 days at 23°C prior to placing in test environments. The models were stored for 3 days at the test temperature prior to testing.

TABLE 8

SUMMARY OF NOTES TAKEN DURING STRIPPING OF CONCRETE/CONCRETE SPECIMENS

MATERIAL	SPECIMEN WIDTH (IN)	REMARKS
F1	9	Specimen very difficult to separate. Material flexible and adheres very well to concrete. Concrete/Adhesive failure.
F3	18	Specimen very difficult to separate. Material flexible and has very good adhesion to concrete.
333	9	Material rigid. 100% concrete failure.
WTR	9 and 18	Specimens very easy to separate. Material flexible. Cohesive failure within material.
ELMF	9 and 18	Specimens very easy to separate. Material flexible. Adhesive failure.
LV4	9	Specimen difficult to separate. Material foams within crack. Adhesive/Cohesive/Concrete failure.
LV3	9 and 18	Specimen difficult to separate. Material foams within crack and is pliable. Adhesive/Cohesive failure.
8132	9	Material rigid. 100% concrete failure.

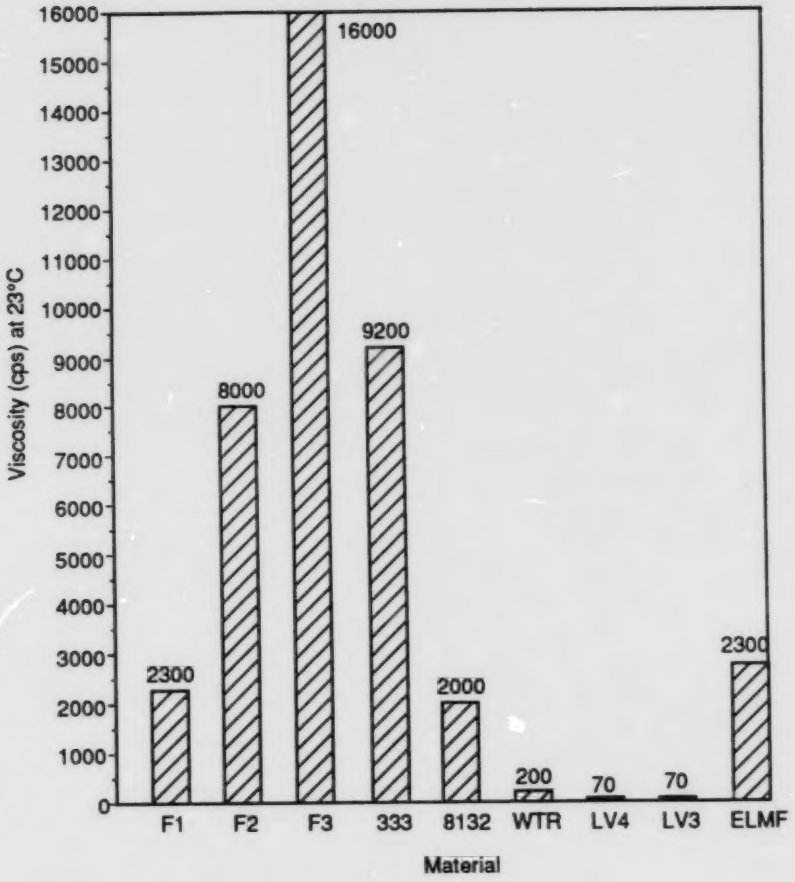


FIGURE 1

VISCOSITY OF ORGANIC GROUTS AS SUPPLIED BY MANUFACTURER

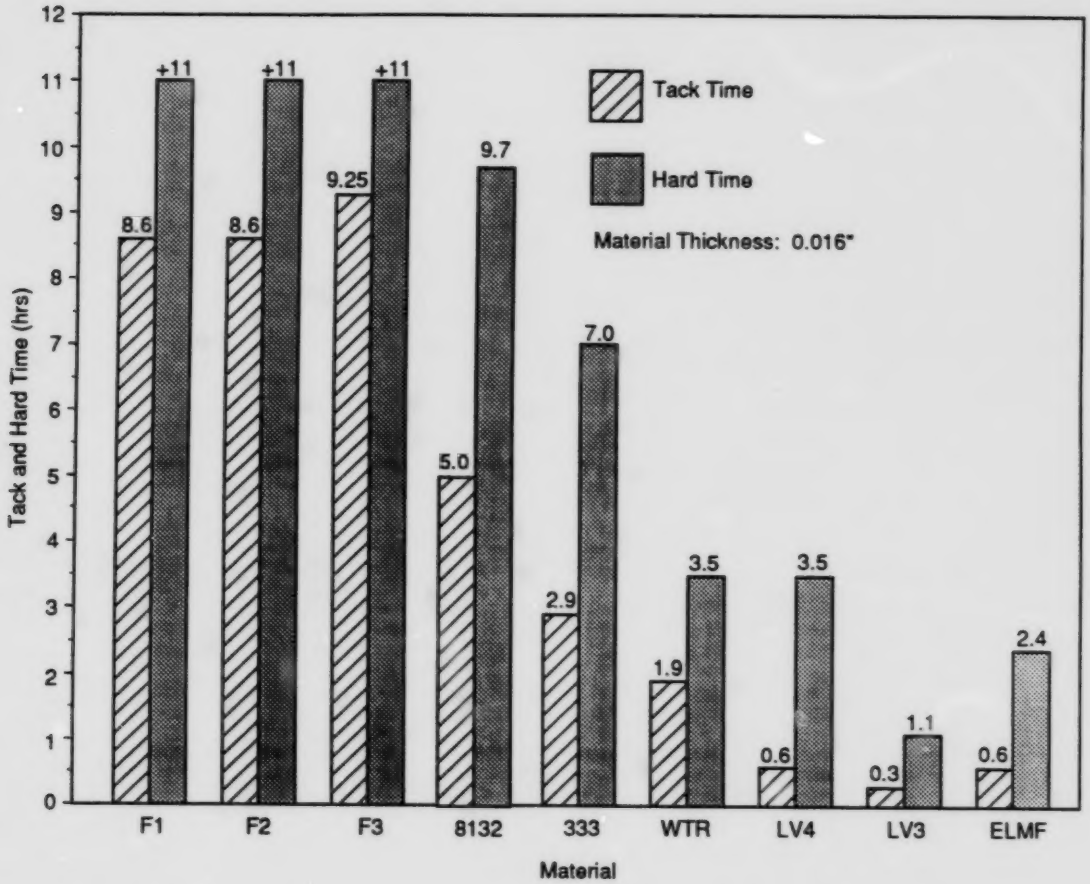


FIGURE 2

TACK AND HARD TIMES OF ORGANIC GROUTS

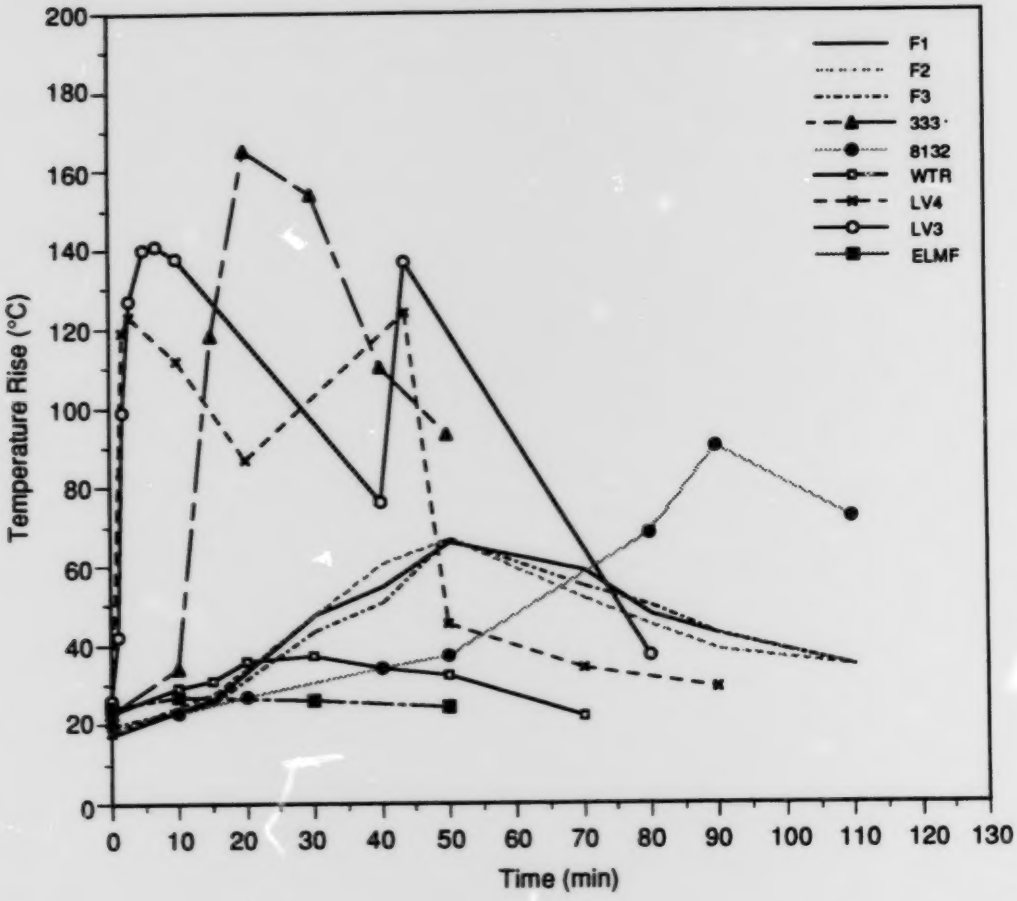
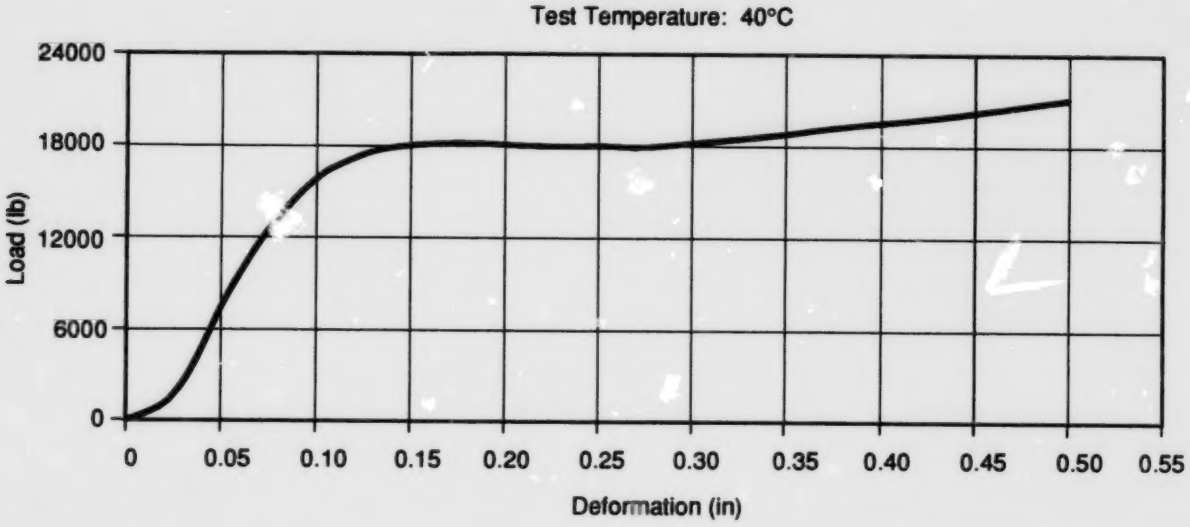
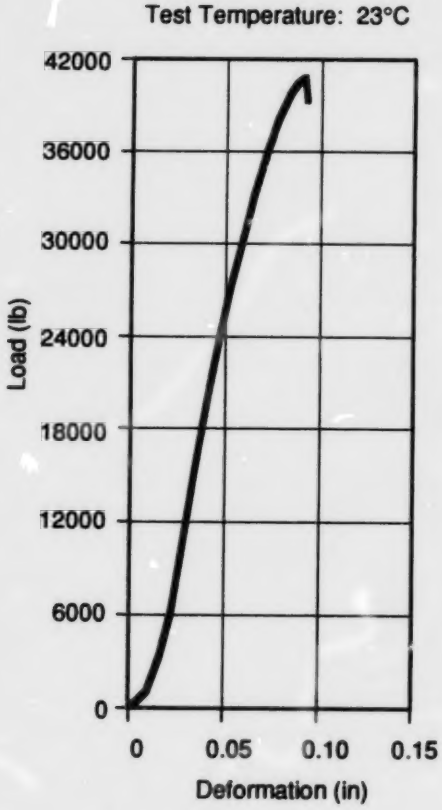


FIGURE 3

TEMPERATURE RISE OF ORGANIC GROUTS





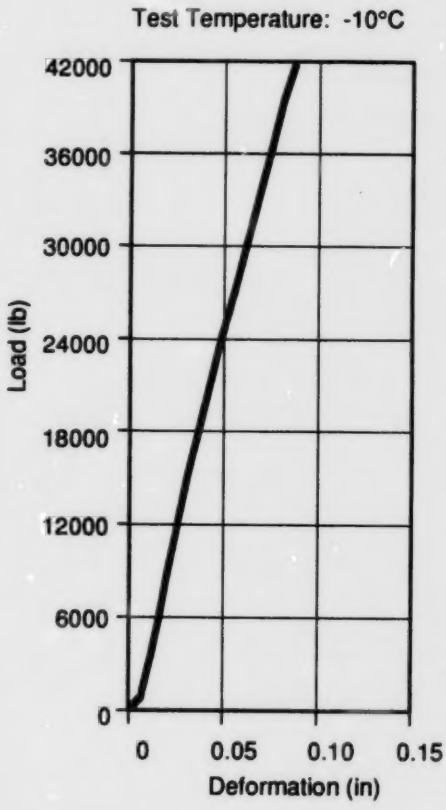


FIGURE 4

COMPRESSIVE LOAD DEFORMATION CHARACTERISTICS UNDER DIFFERENT EXPOSURE CONDITIONS CAPWELD 333

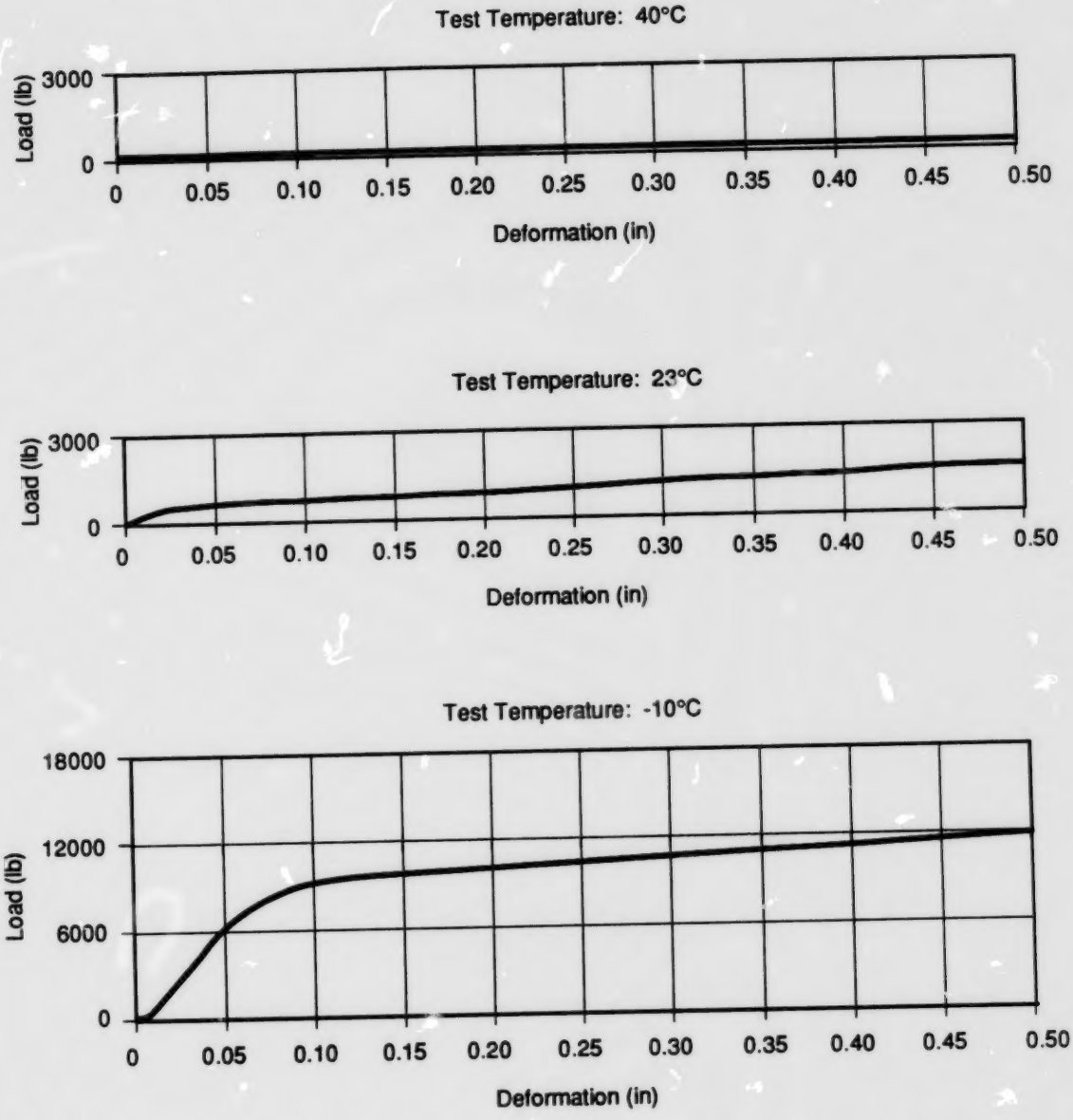
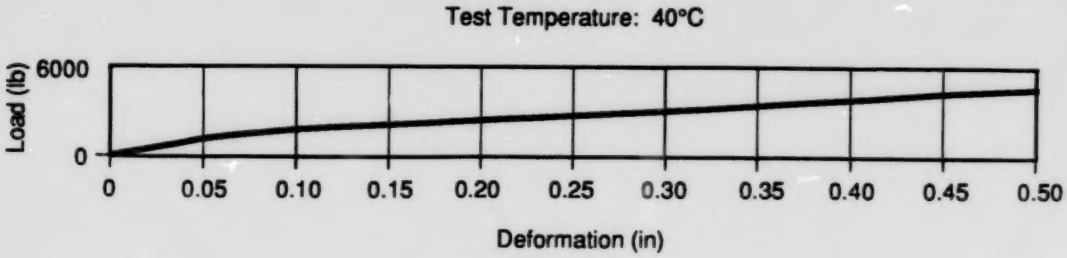
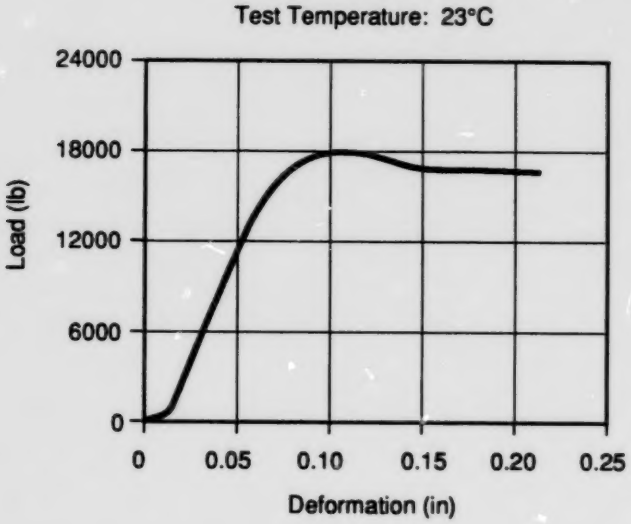


FIGURE 5

COMPRESSIVE LOAD DEFORMATION CHARACTERISTICS UNDER DIFFERENT EXPOSURE CONDITIONS CAPWELD F3 EPOXY





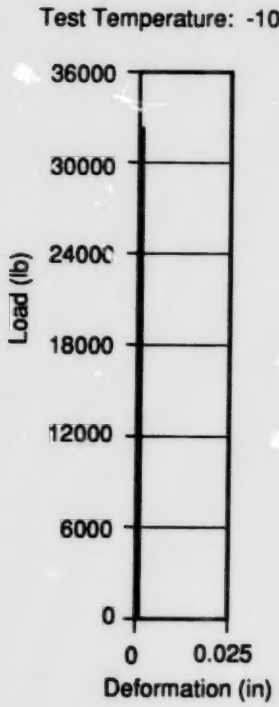


FIGURE 6

COMPRESSIVE LOAD DEFORMATION CHARACTERISTICS UNDER DIFFERENT EXPOSURE CONDITIONS 8132 EPOXY

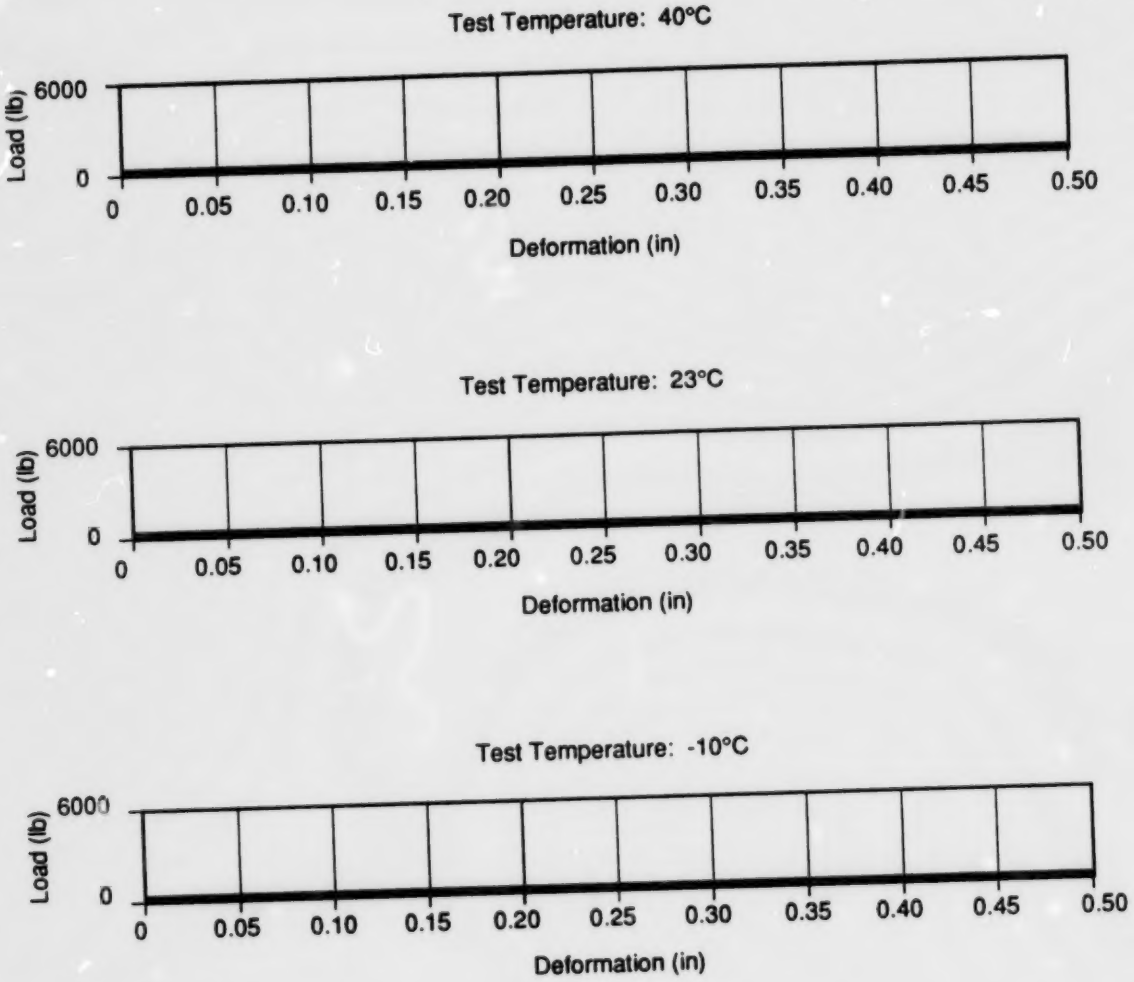


FIGURE 7

COMPRESSIVE LOAD DEFORMATION CHARACTERISTICS UNDER DIFFERENT EXPOSURE CONDITIONS WTR POLYURETHANE

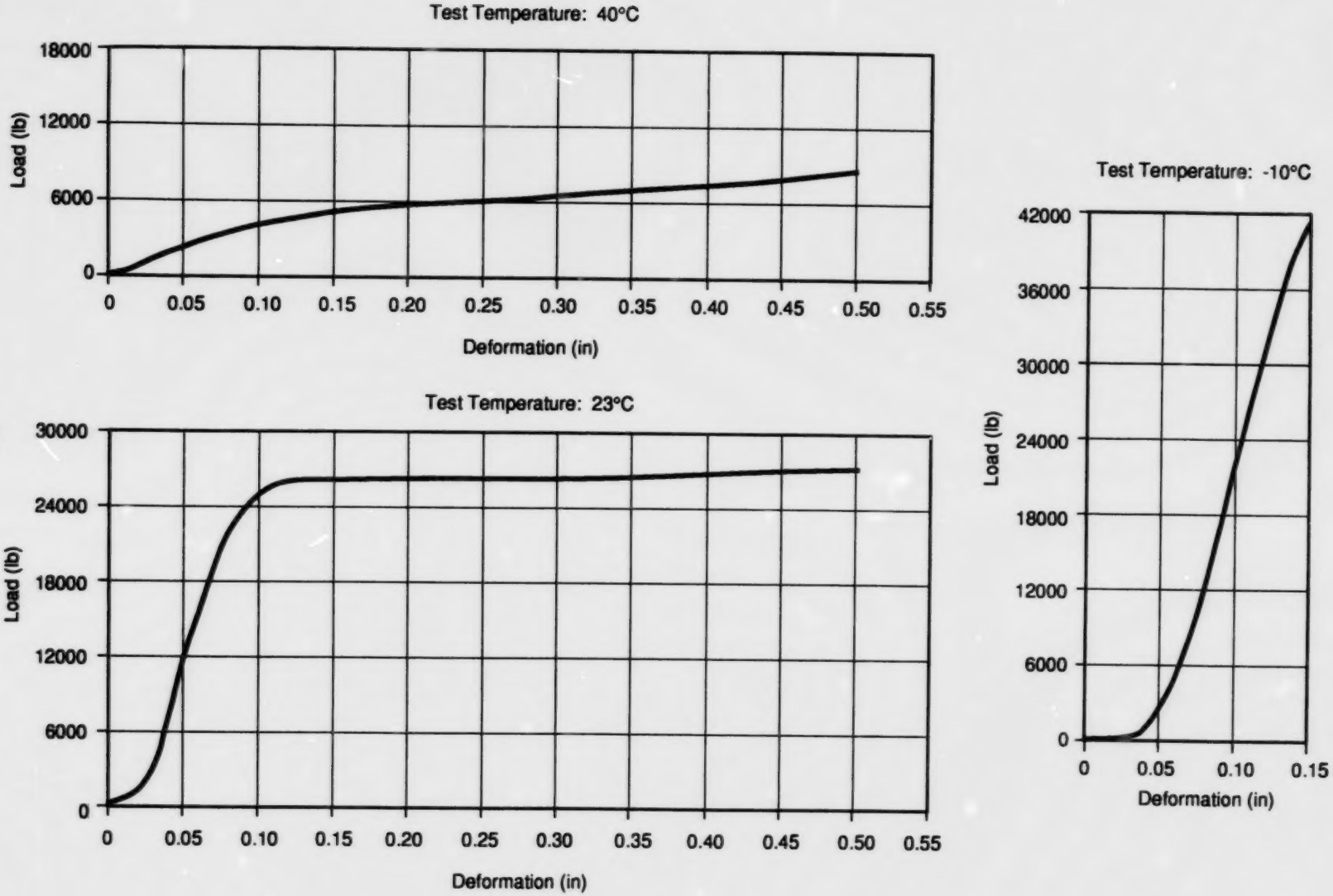
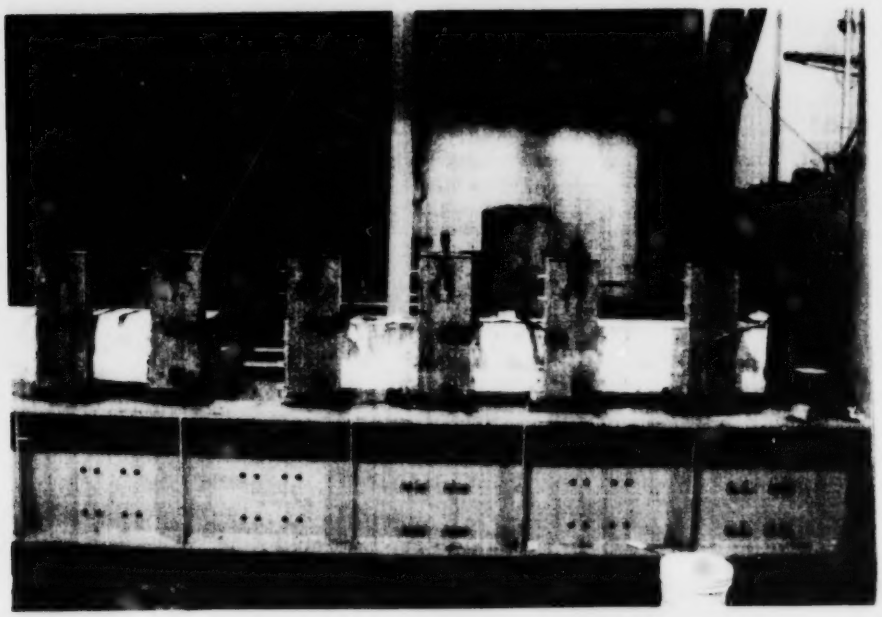


FIGURE 8

COMPRESSIVE LOAD DEFORMATION CHARACTERISTICS UNDER DIFFERENT EXPOSURE CONDITIONS LV4 POLYURETHANE

Injection ports installed between plexiglas and concrete
Plexiglas placed against concrete with and without shims to simulate different size cracks

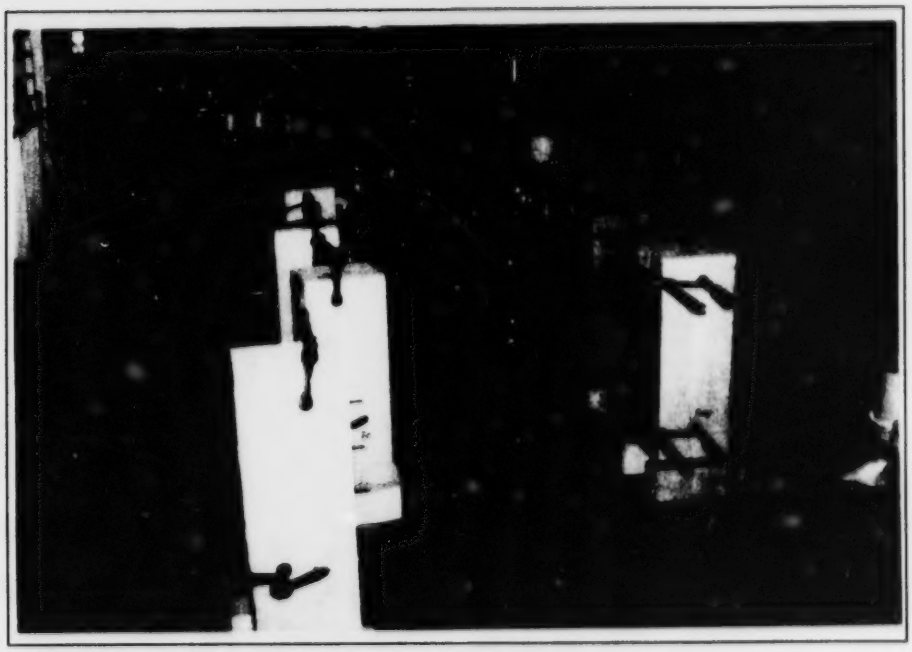


Overview of plexiglas/concrete models prior to injection

FIGURE 9

SETTING UP PLEXIGLAS/CONCRETE MODELS FOR INJECTION

Plexiglas/Concrete Models



Concrete/Concrete Models

FIGURE 10

GENERAL TEST SETUP OF PLEXIGLAS/CONCRETE AND CONCRETE/CONCRETE MODELS

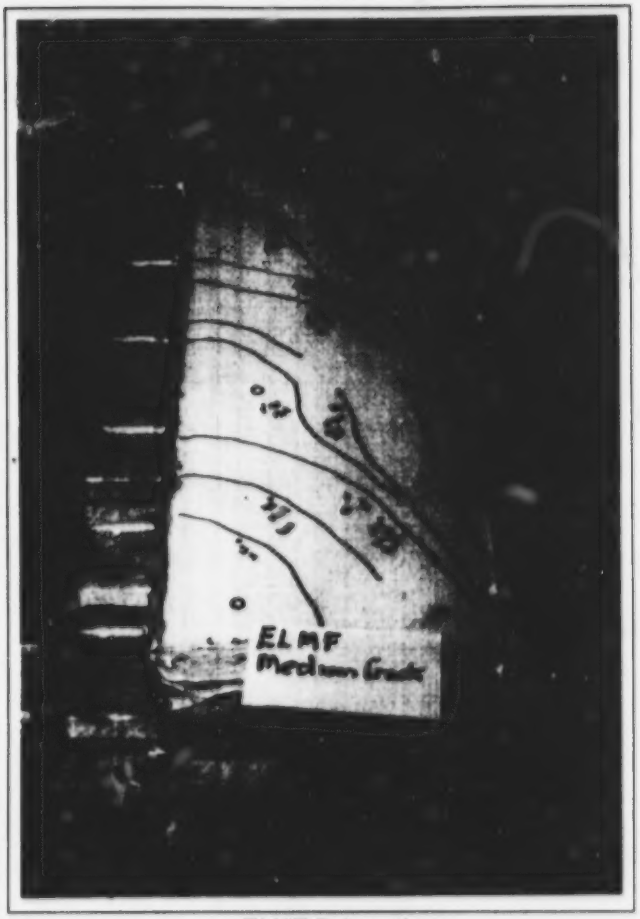
ELMF Polyurethane

8132 Epoxy - Note material drained out of crack

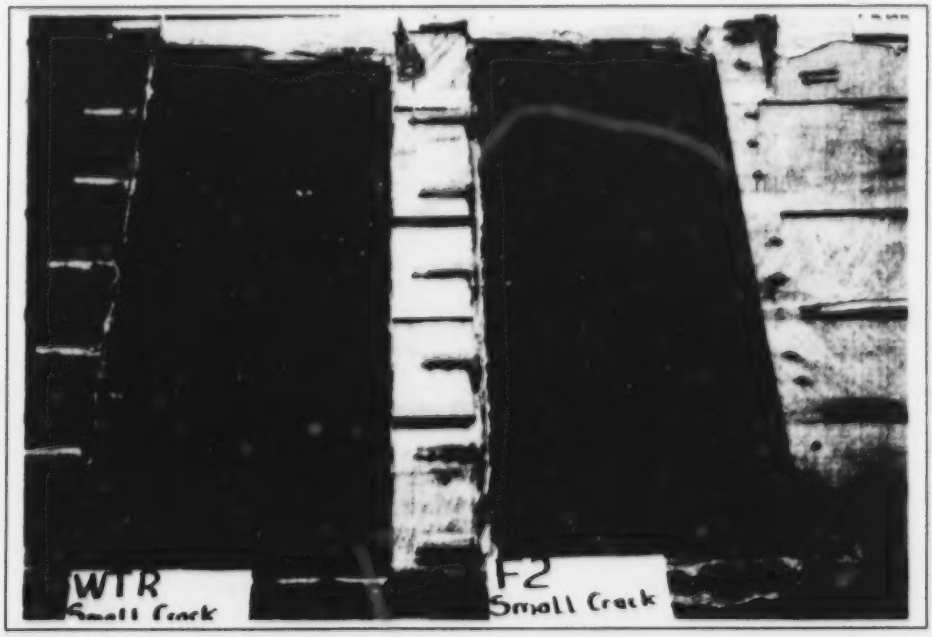
FIGURE 11

VIEW OF PLEXIGLAS/CONCRETE SPECIMENS DURING INJECTION

F3 Epoxy



ELMF Polyurethane



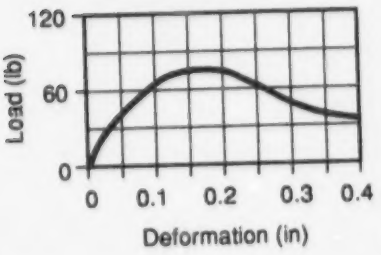
WTR Polyurethane

F2 Epoxy

FIGURE 12

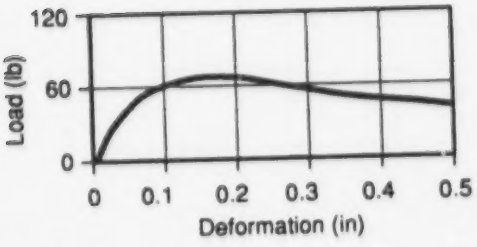
VIEW OF PLEXIGLAS/CONCRETE SPECIMENS AFTER ALLOWING MATERIAL TO CURE

Test Temperature: 40°C



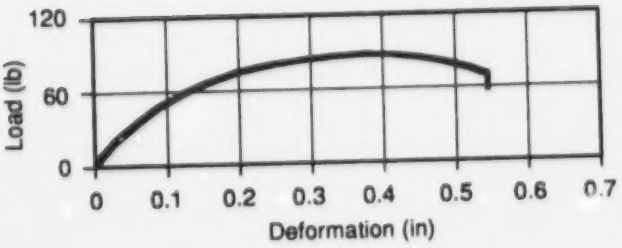
Bond Strength: 0.23 MPa
Elongation: 11% - 19%
Failure Mode: 10% Conc.
90% Bond

Test Temperature: 23°C



Bond Strength: 0.16 MPa
Elongation: 5% - 8%
Failure Mode: 10% Conc.
90% Bond

Test Temperature: -10°C

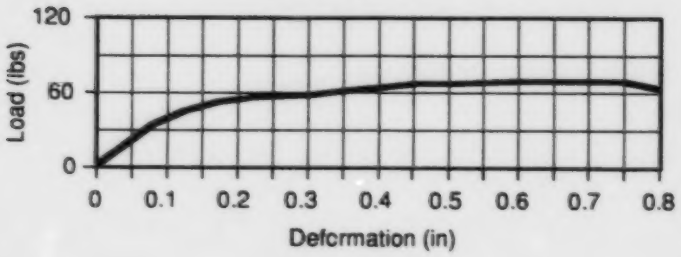


Bond Strength: 0.23 MPa
Elongation: 17% - 26%
Failure Mode: 10% Conc.
90% Bond

FIGURE 13

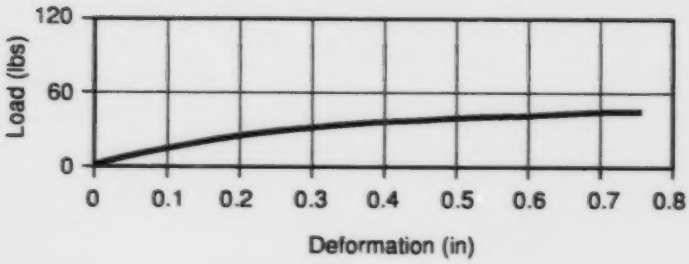
EFFECT OF DIFFERENT EXPOSURE TEMPERATURES ON TENSILE ELONGATION AND BOND STRENGTH MATERIAL: POLYURETHANE ELMF

Test Temperature: 40°C



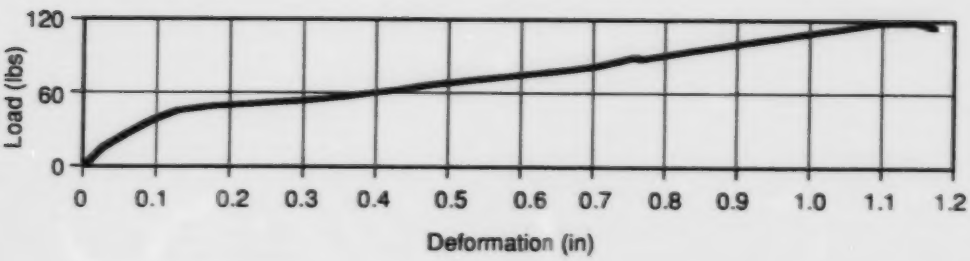
Bond Strength: 0.21 MPa
Elongation: 64% - 128%
Failure Mode: 10% Conc.
90% Bond

Test Temperature: 23°C



Bond Strength: 0.155 MPa
Elongation: 56% - 102%
Failure Mode: 100% Bond

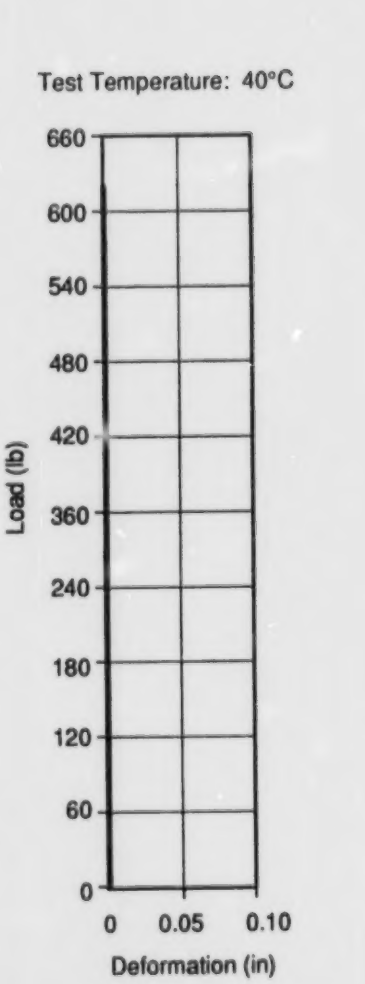
Test Temperature: -10°C



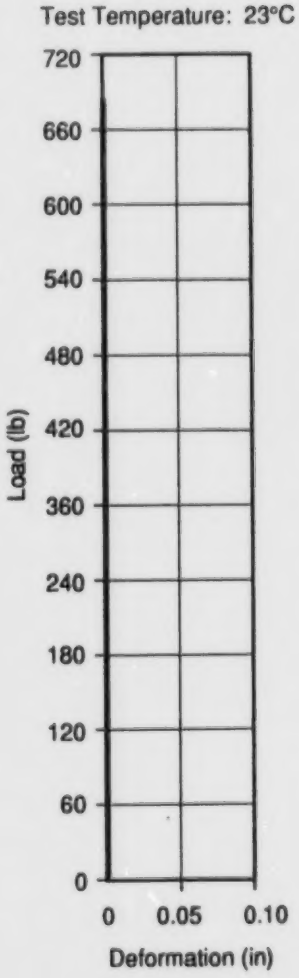
Bond Strength: 0.35 MPa
Elongation: 94% - 185%
Failure Mode: 30% Conc.
70% Bond

FIGURE 14

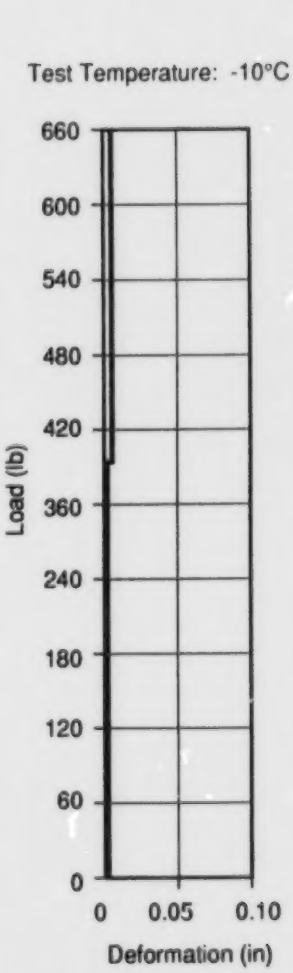
EFFECT OF DIFFERENT EXPOSURE TEMPERATURES ON TENSILE ELONGATION AND BOND STRENGTH MATERIAL: POLYURETHANE POLYCAST WTR



Bond Strength: 1.61 MPa
Elongation: 0%
Failure Mode: 100% Conc.



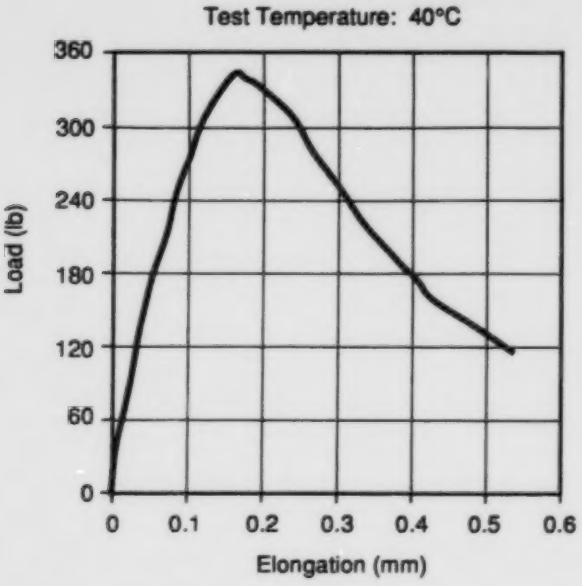
Bond Strength: 1.8 MPa
Elongation: 0%
Failure Mode: 100% Conc.



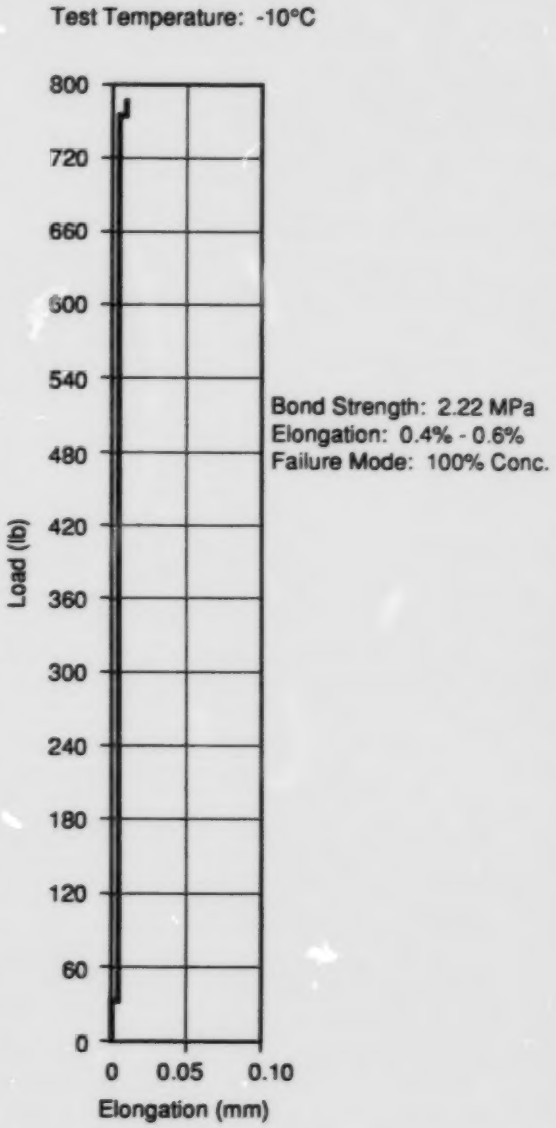
Bond Strength: 1.73 MPa
Elongation: 0%
Failure Mode: 100% Conc.

FIGURE 15

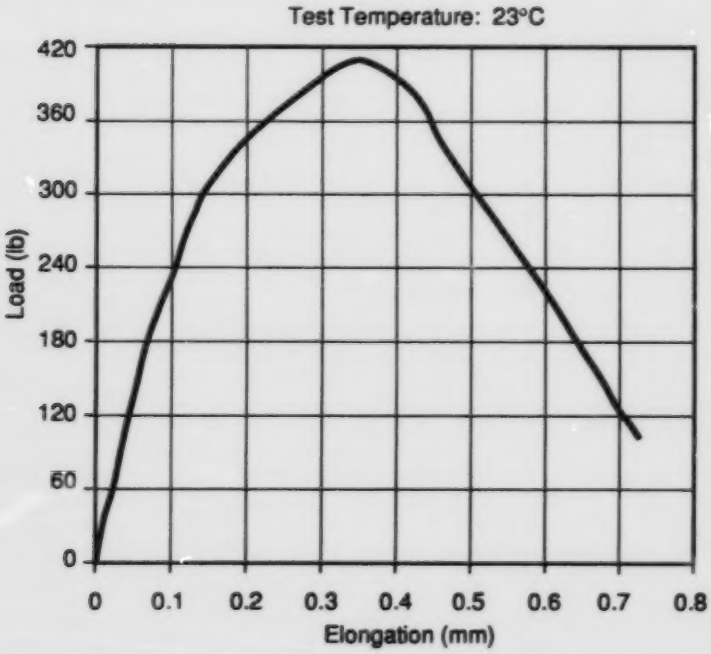
EFFECT OF DIFFERENT EXPOSURE TEMPERATURES ON TENSILE ELONGATION AND BOND STRENGTH CAPWELD 333 EPOXY



Bond Strength: 1.0 MPa
Elongation: 4% - 5%
Failure Mode: 20% Conc.
80% Bond



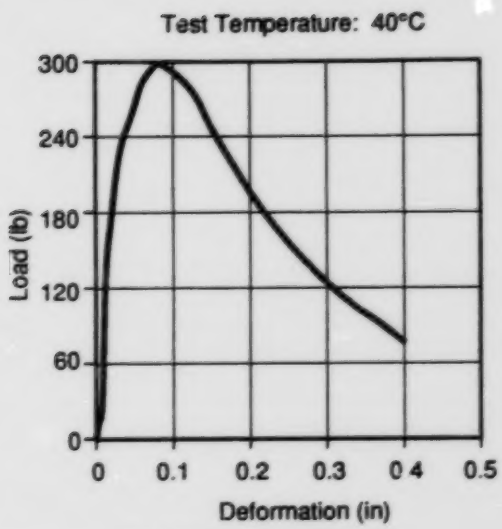
Bond Strength: 2.22 MPa
Elongation: 0.4% - 0.6%
Failure Mode: 100% Conc.



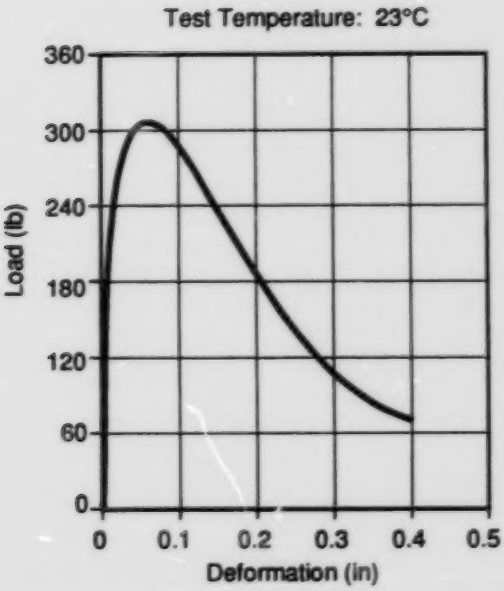
Bond Strength: 1.19 MPa
Elongation: 9% - 12%
Failure Mode: 20% Conc.
80% Bond

FIGURE 16

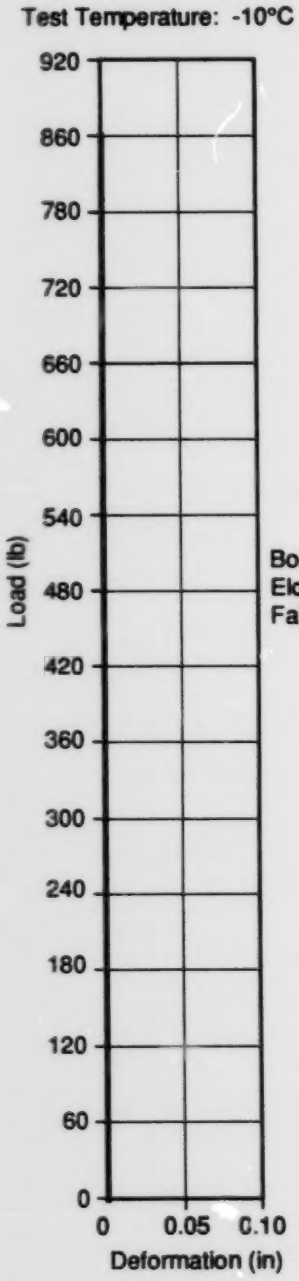
EFFECT OF DIFFERENT EXPOSURE TEMPERATURES ON TENSILE ELONGATION AND BOND STRENGTH MATERIAL: EPOXY CAPWELD F3



Bond Strength: 0.85 MPa
Elongation: 5% - 13%
Failure Mode: 30% Conc.
70% Bond



Bond Strength: 0.88 MPa
Elongation: 7% - 11%
Failure Mode: 20% Conc.
80% Bond



Bond Strength: 2.22 MPa
Elongation: 0.4% - 0.6%
Failure Mode: 100% Conc.

FIGURE 17

EFFECT OF DIFFERENT EXPOSURE TEMPERATURES ON TENSILE ELONGATION AND BOND STRENGTH MATERIAL: EPOXY F1

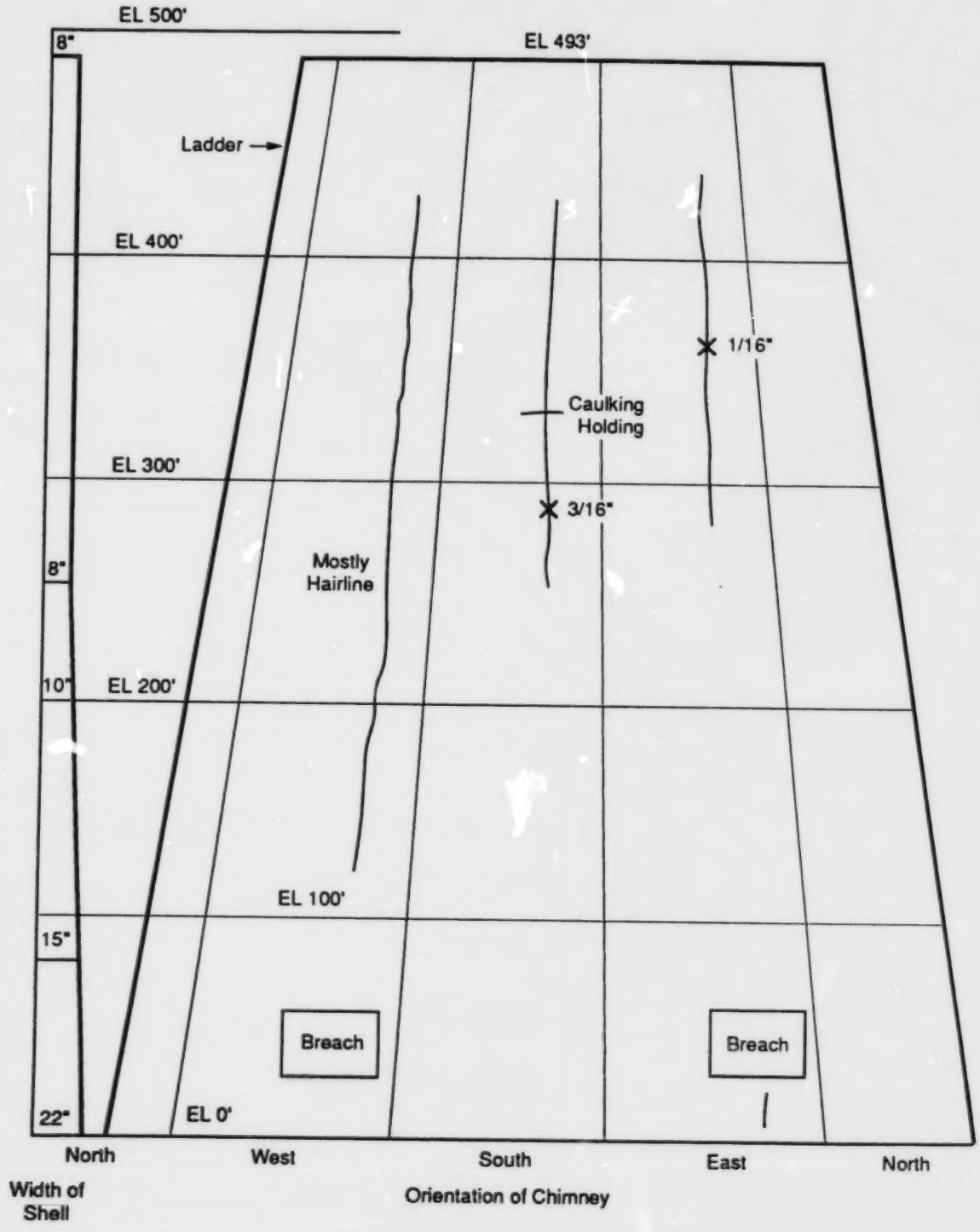


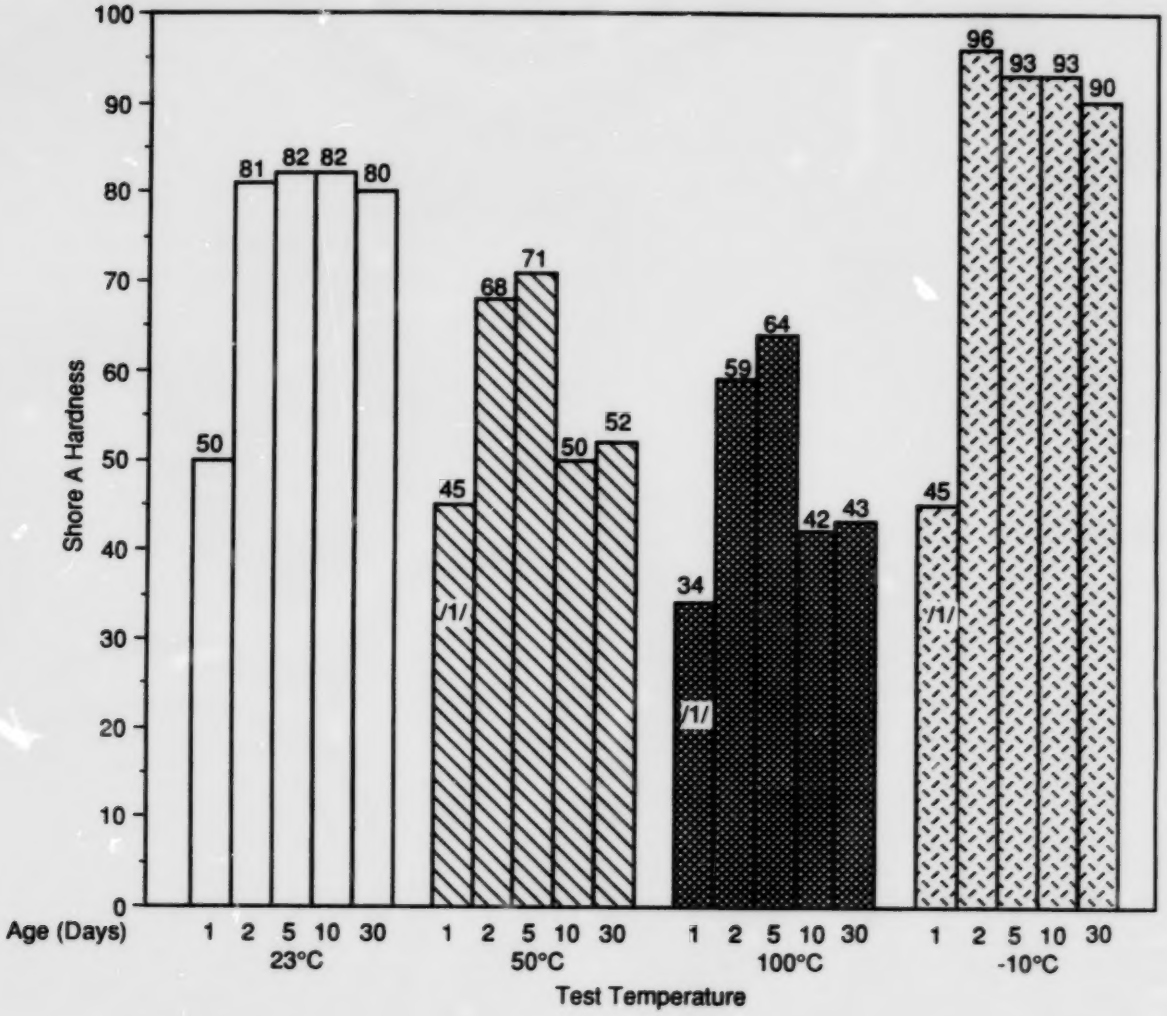
FIGURE 18

LAKEVIEW TGS CHIMNEY NO. 3
CONDITION SURVEY
EXTERIOR SURFACE - CONCRETE SHELL

APPENDIX A

Shore A and D Durometer Hardness Measurements of Materials Exposed to Different Temperatures

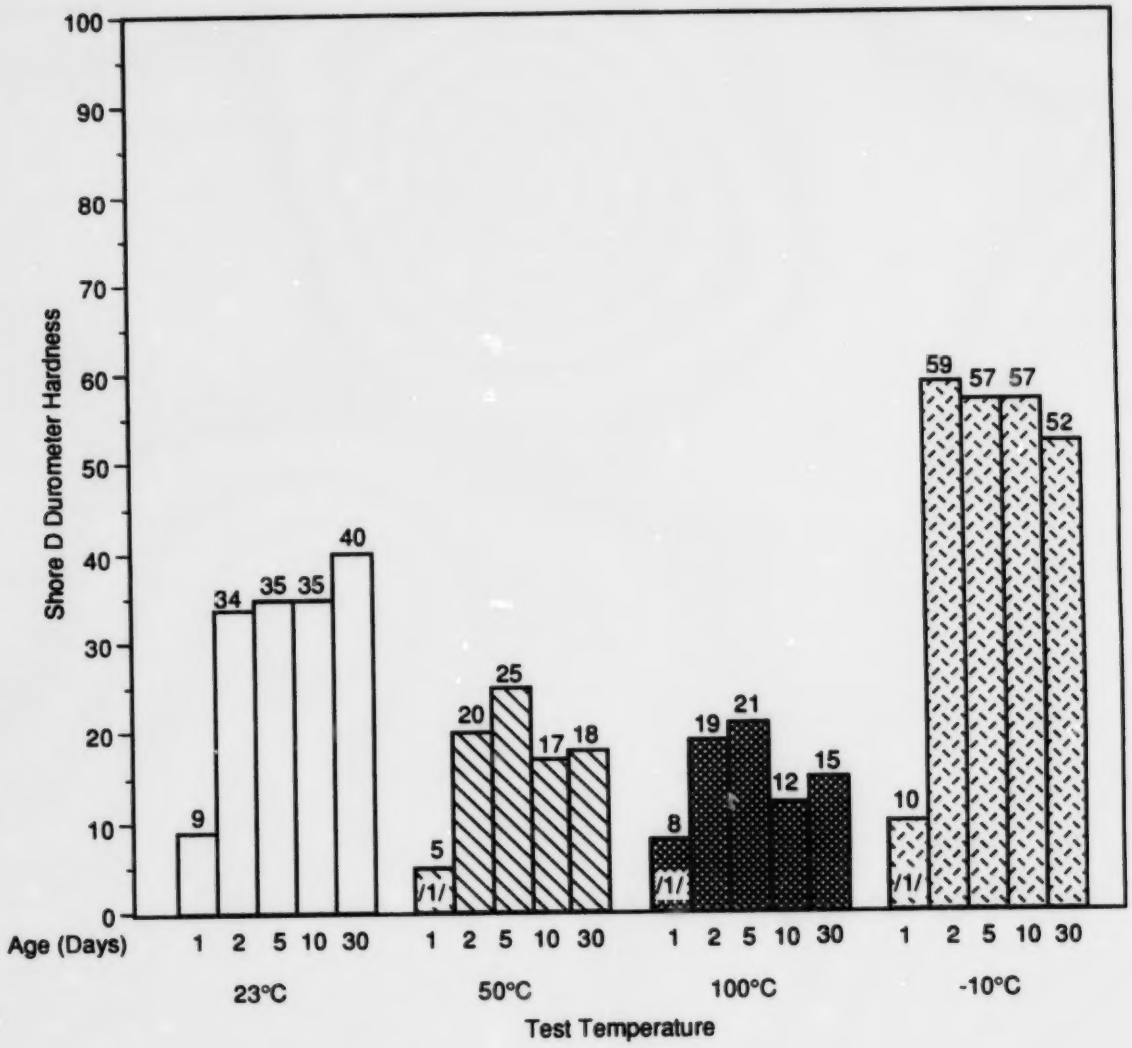
Figure	A-1	Capweld	F1 - Shore A Hardness
	A-2	Capweld	F1 - Shore D Hardness
	A-3	Capweld	F2 - Shore A Hardness
	A-4	Capweld	F2 - Shore D Hardness
	A-5	Capweld	F3 - Shore A Hardness
	A-6	Capweld	F3 - Shore D Hardness
	A-7	Capweld	333 - Shore A Hardness
	A-8	Capweld	333 - Shore D Hardness
	A-9	Sikadur	8132 - Shore A Hardness
	A-10	Sikadur	8132 - Shore D Hardness
	A-11		WTR - Shore A Hardness
	A-12		LV4 - Shore A Hardness
	A-13		LV4 - Shore D Hardness
	A-14		LV3 - Shore A Hardness
	A-15		LV3 - Shore D Hardness
	A-16		ELMF - Shore A Hardness



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A1

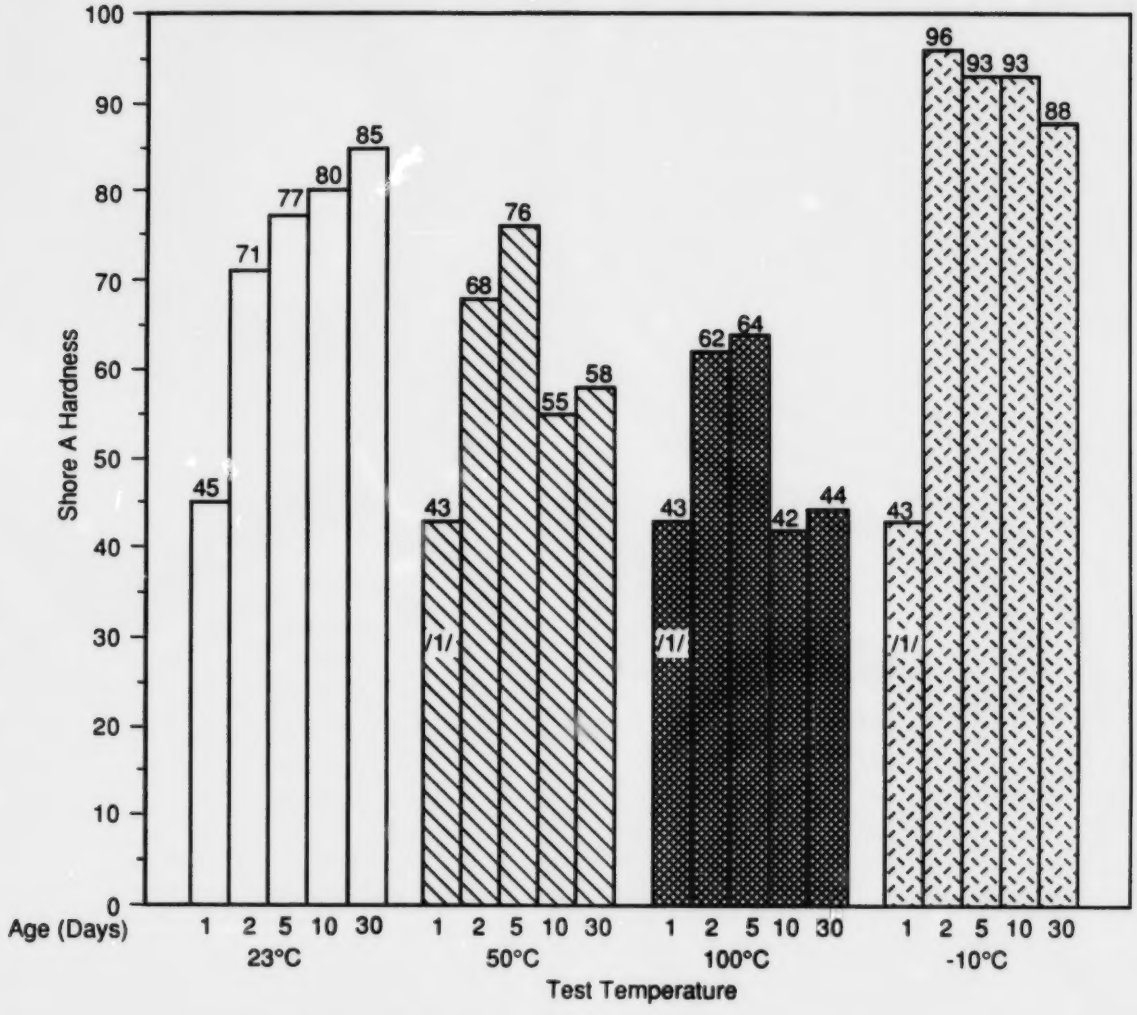
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS CAPWELD F1



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A2

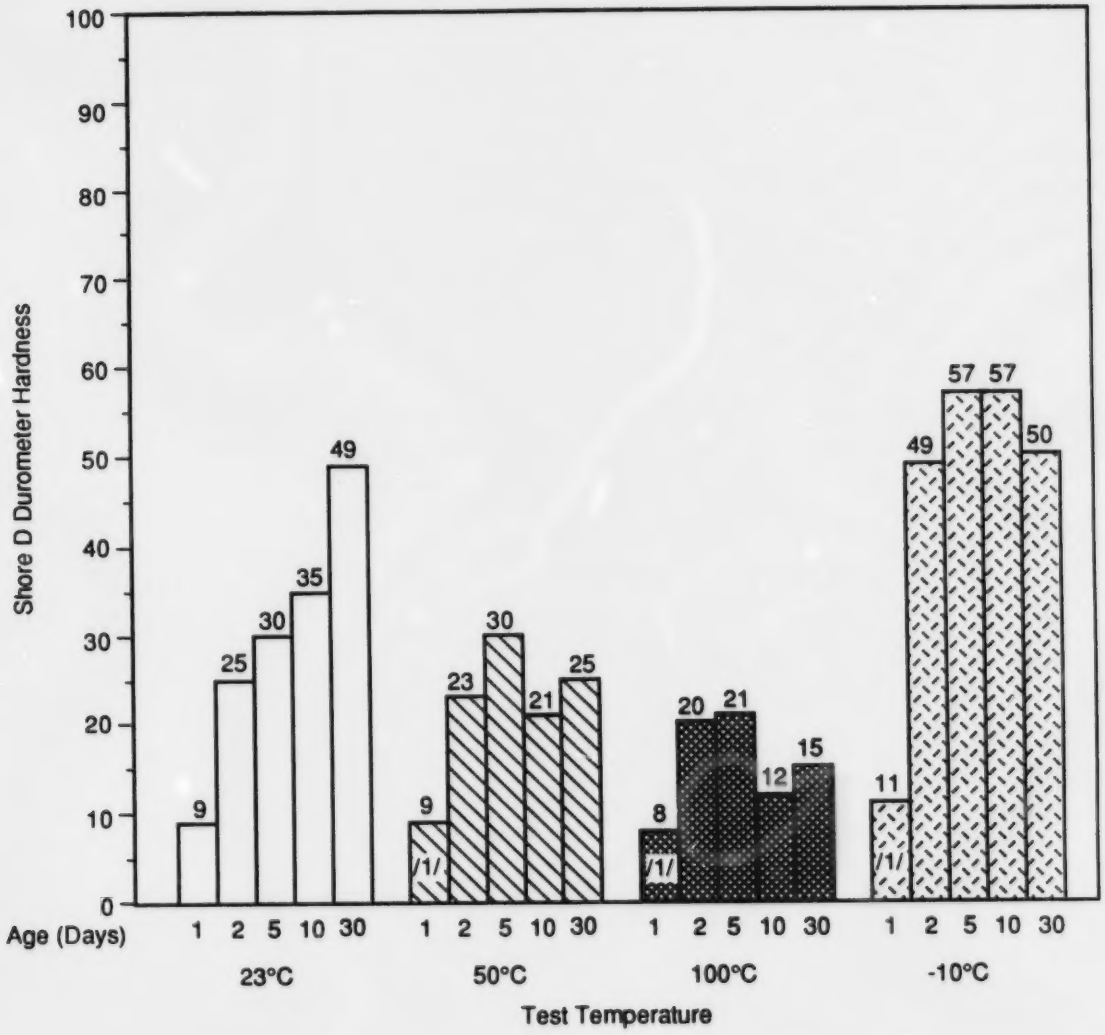
EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS CAPWELD F1



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A3

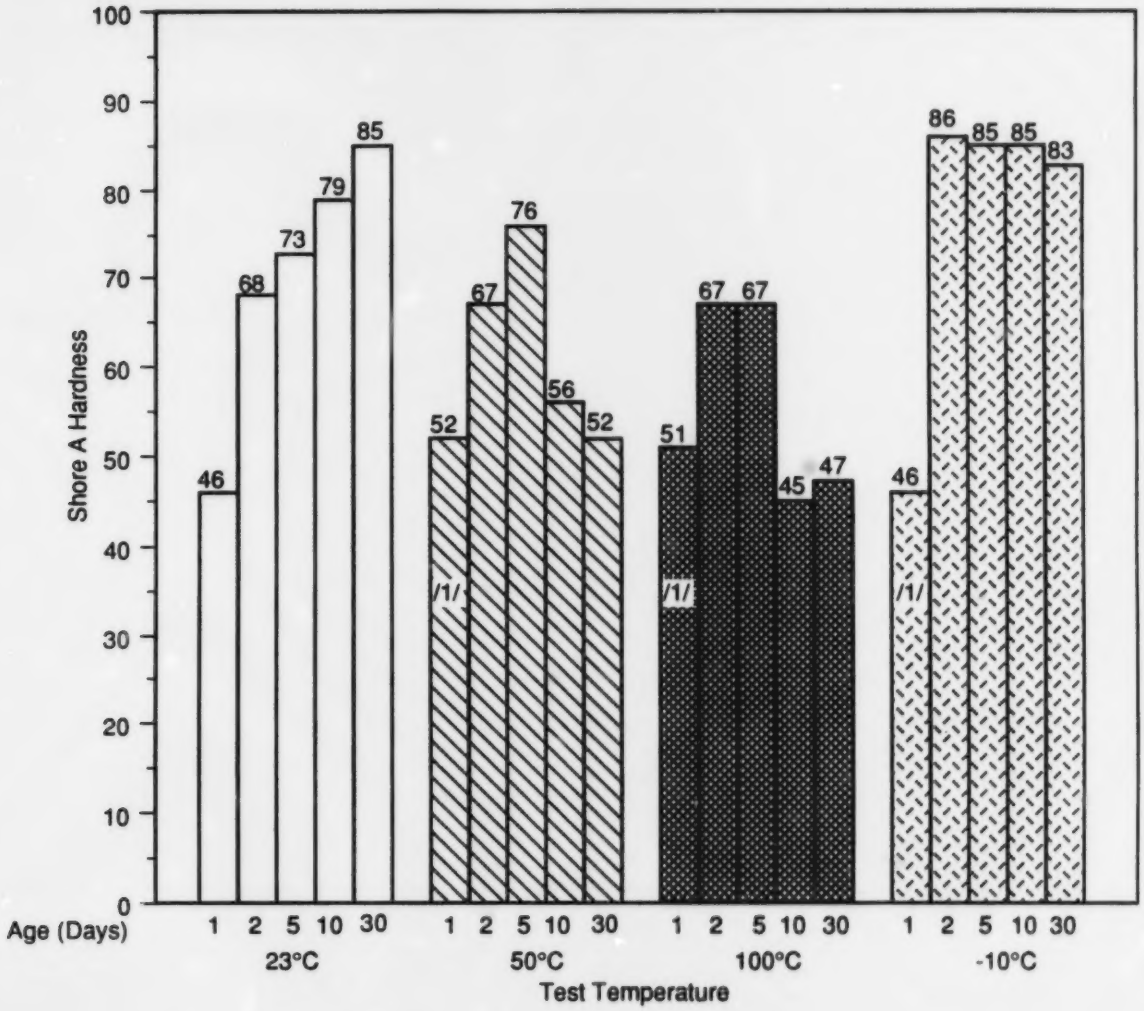
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS CAPWELD F2



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A4

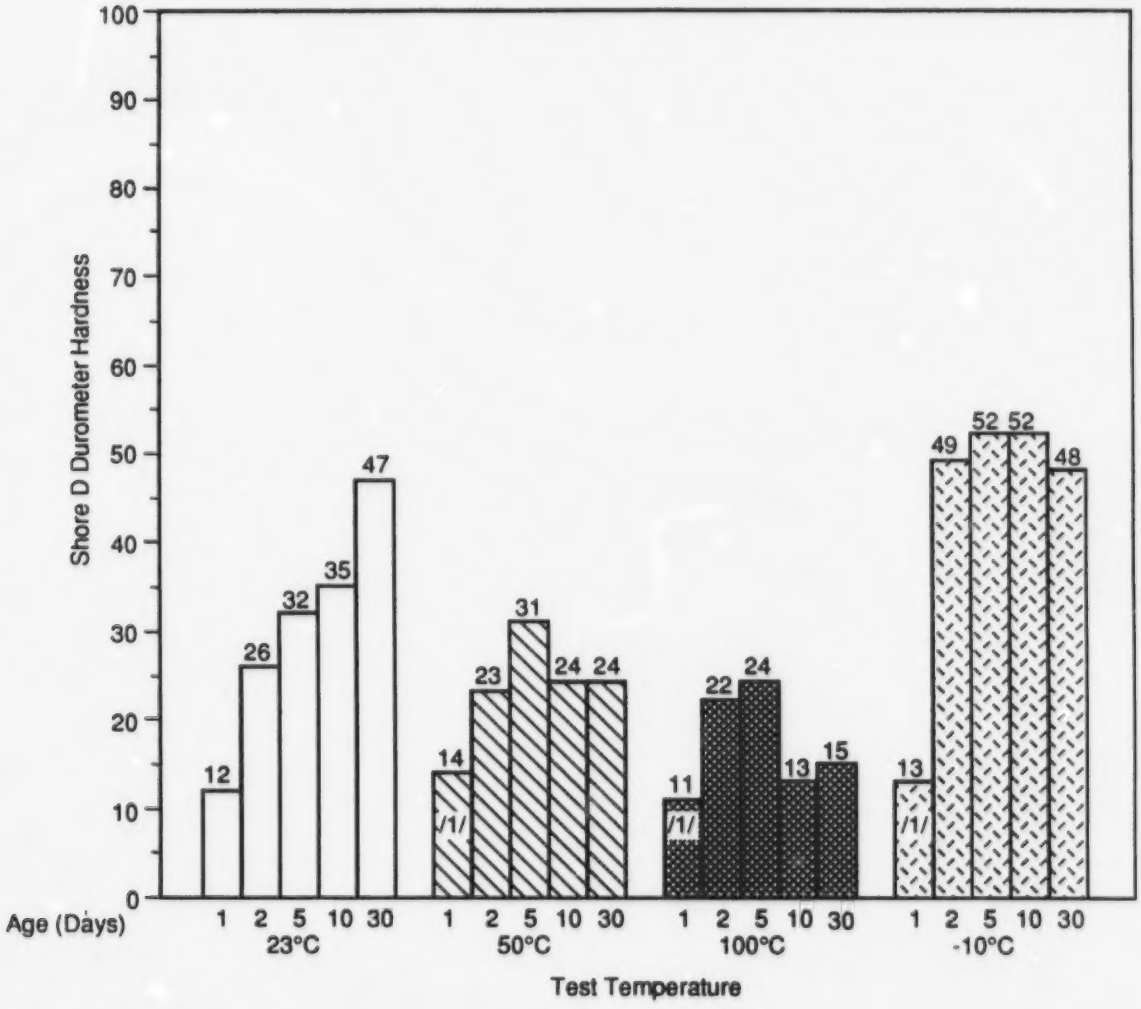
EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS CAPWELD F2



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A5

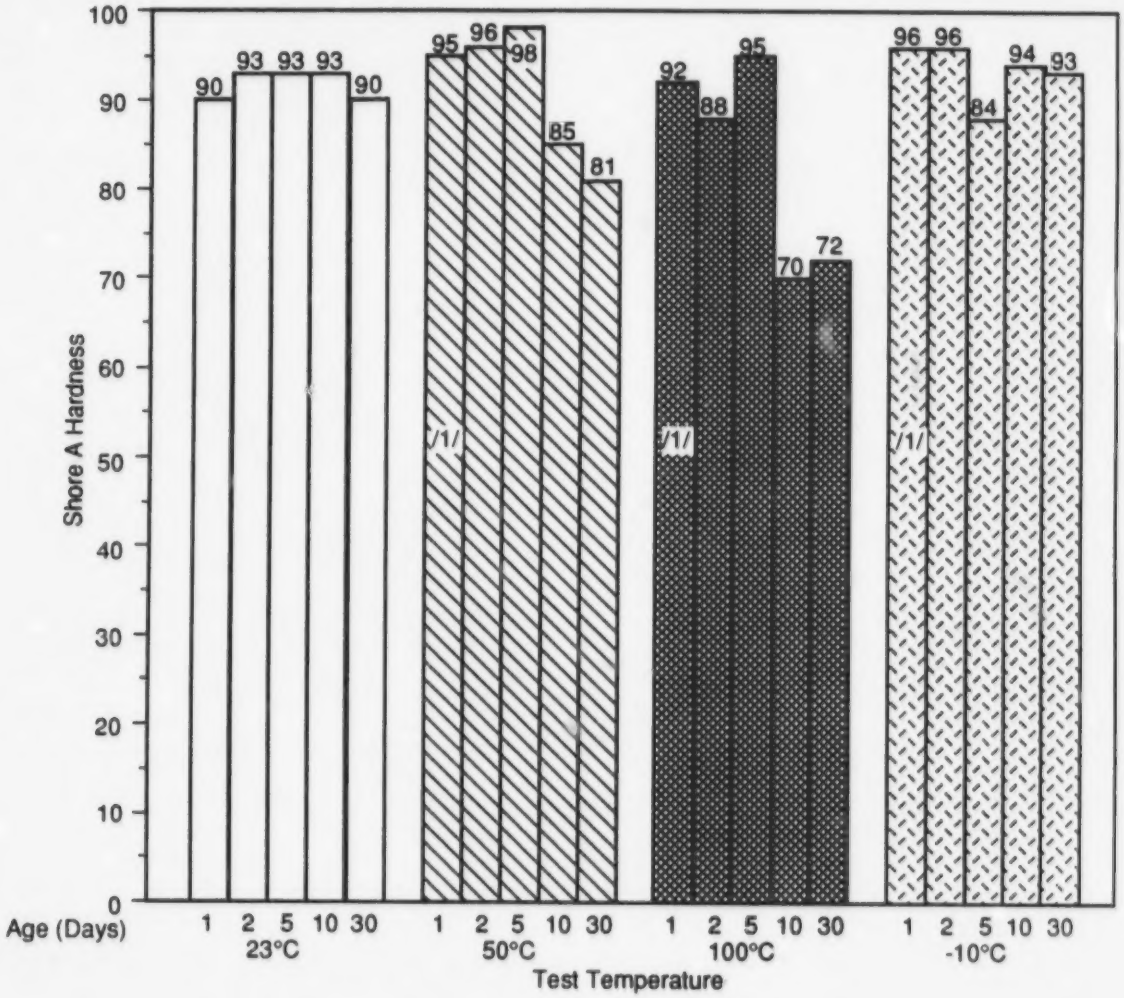
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS CAPWELD F3



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A6

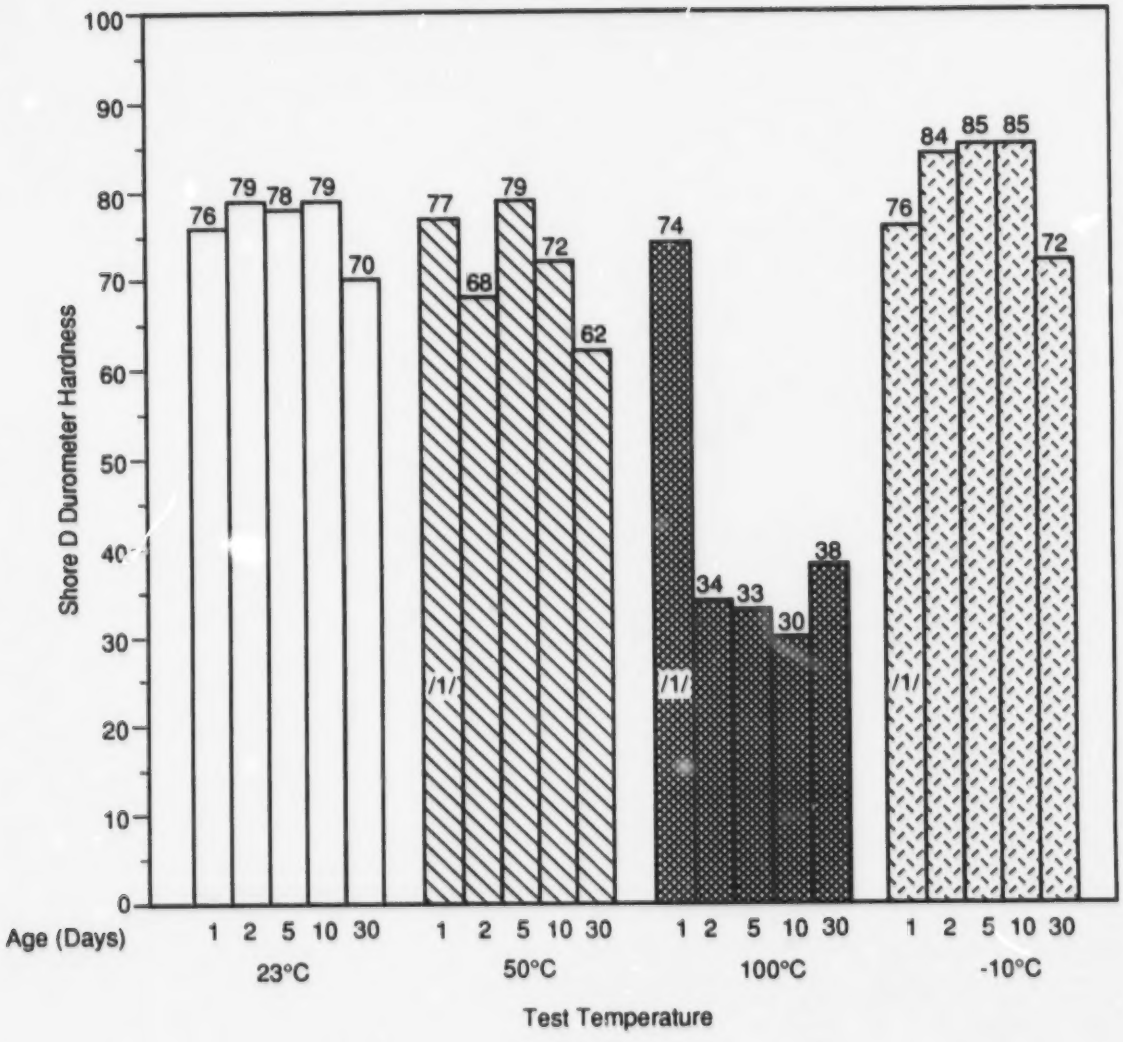
EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS CAPWELD F3



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A7

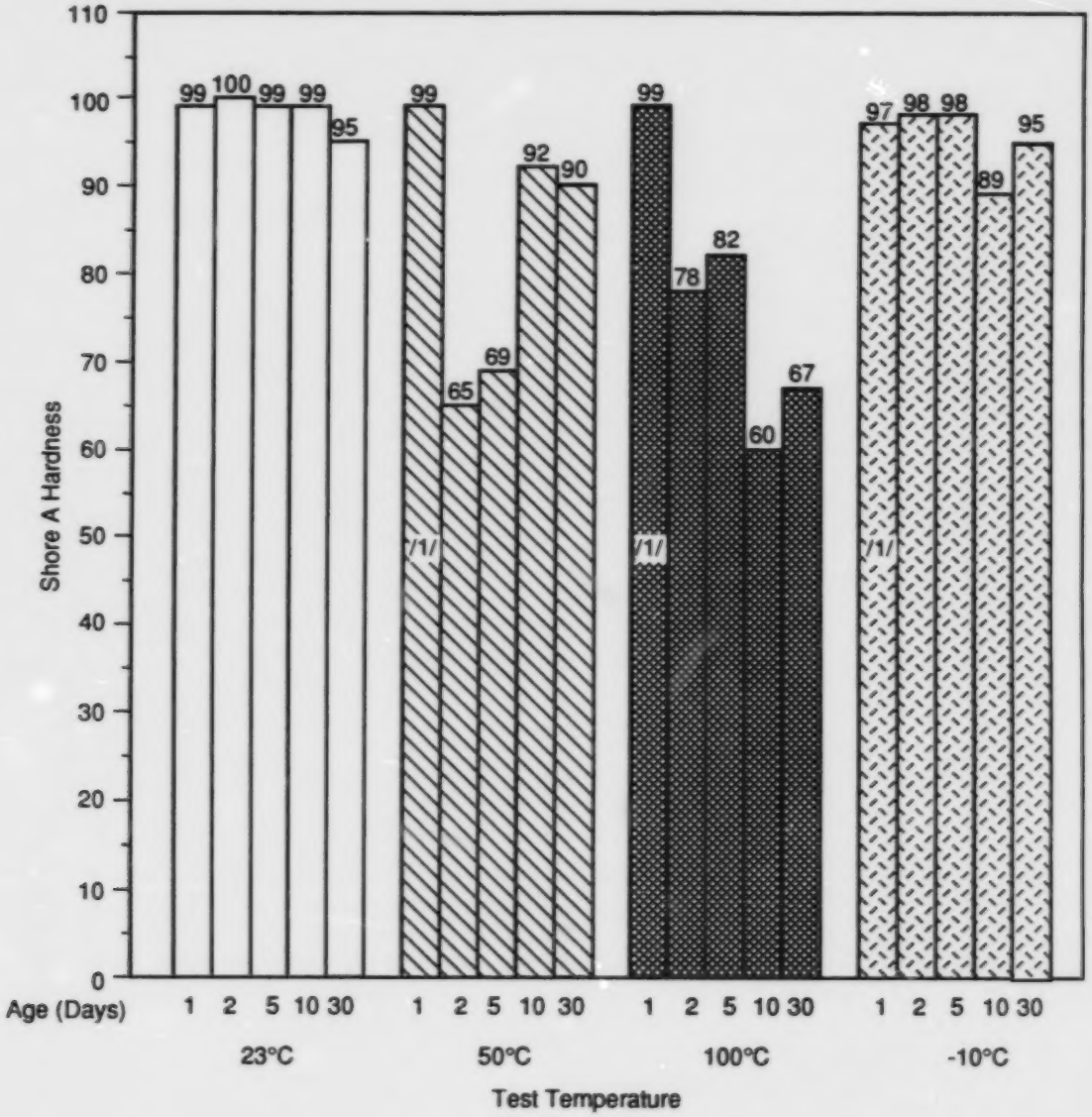
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS CAPWELD 333



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A8

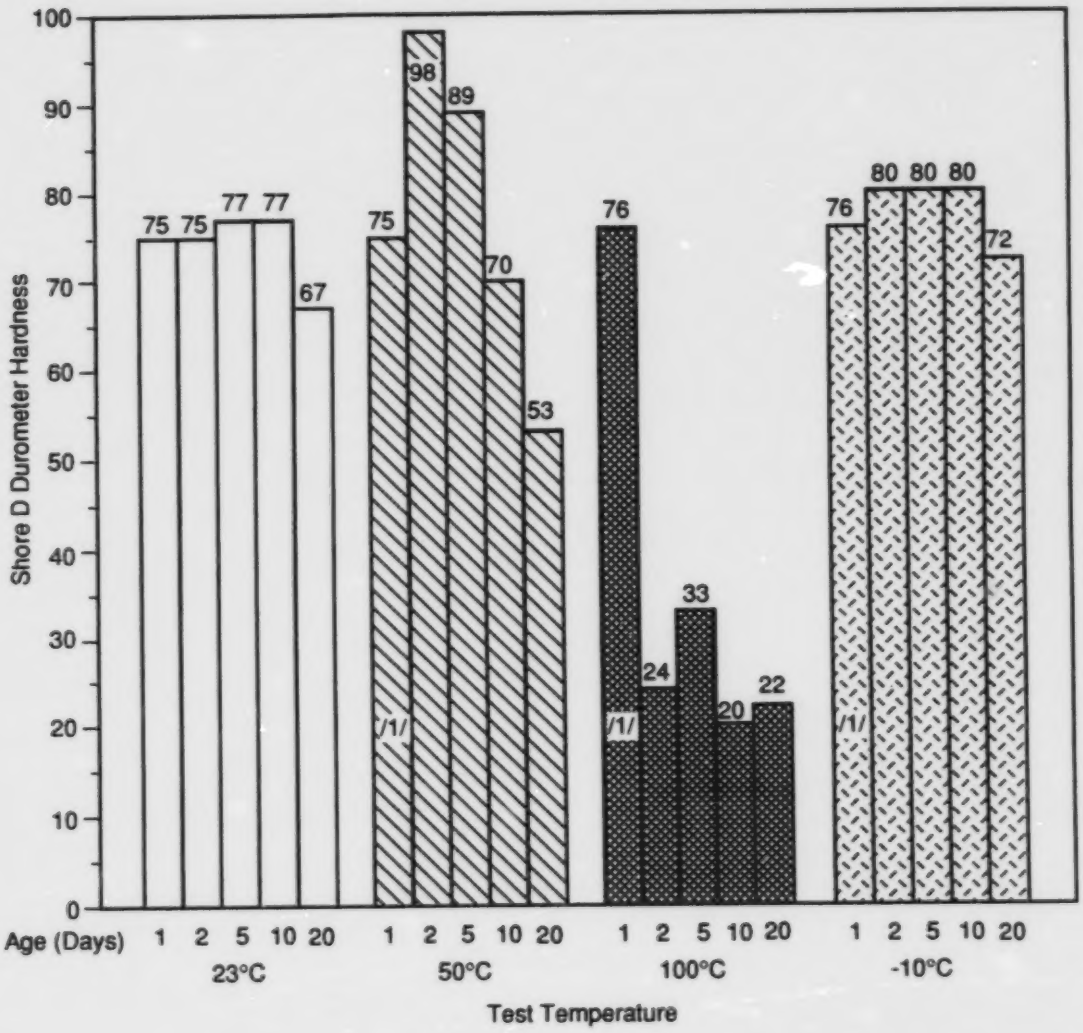
EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS CAPWELD 333



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A9

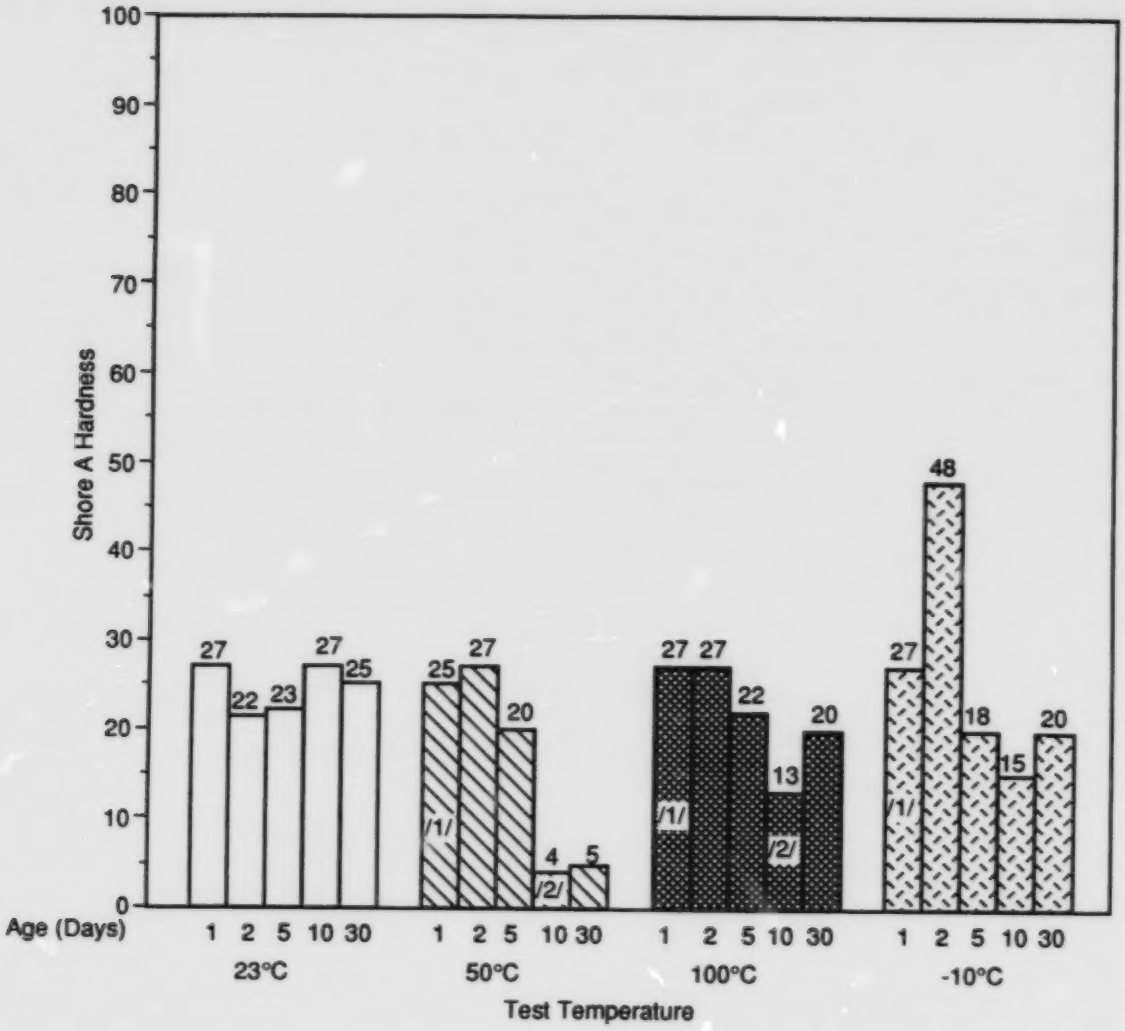
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS 8132



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A10

EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS 8132

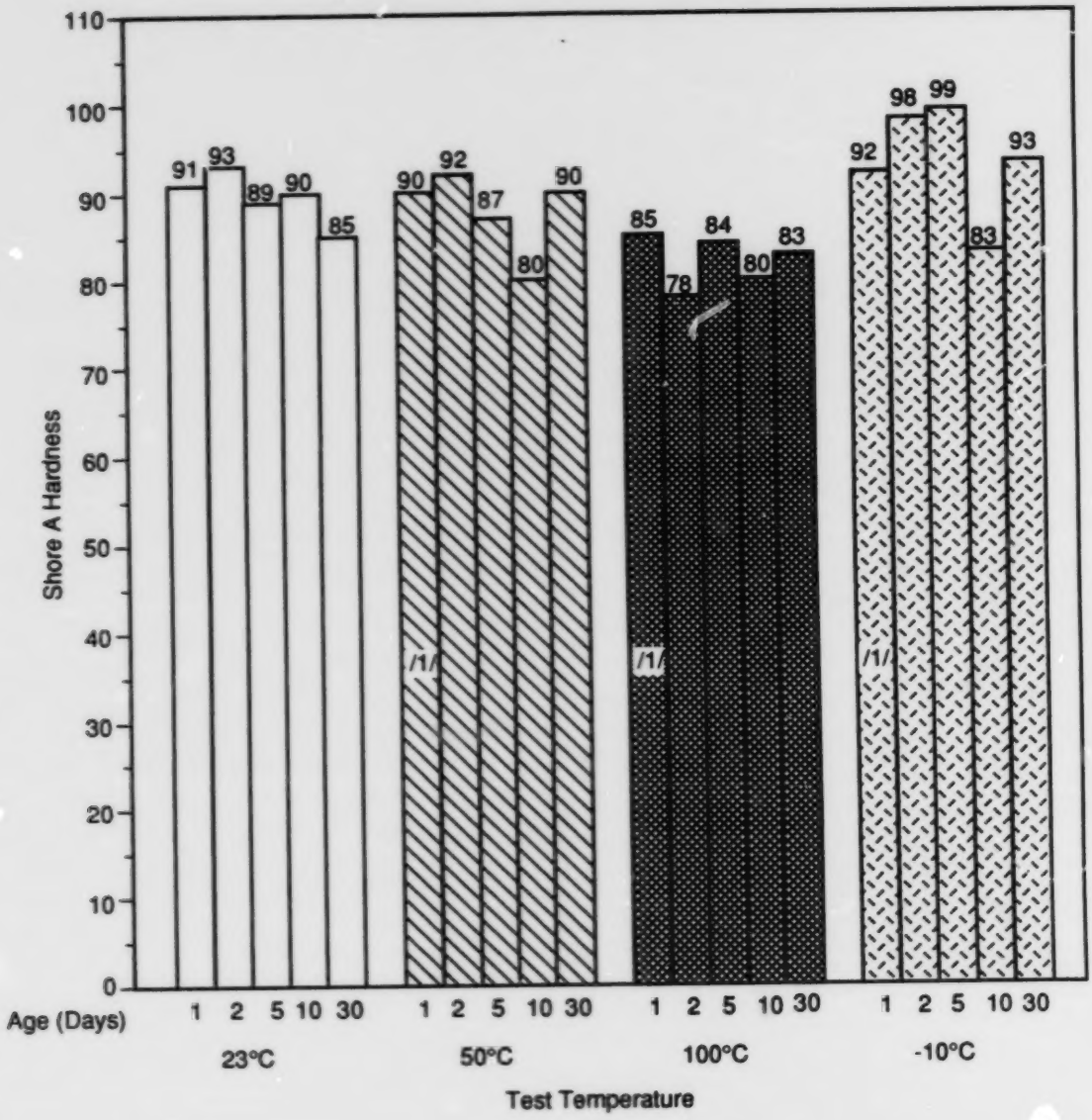


/1/ Initial 24 hour measurement taken at 23°C

/2/ Significant shrinkage in material

FIGURE A11

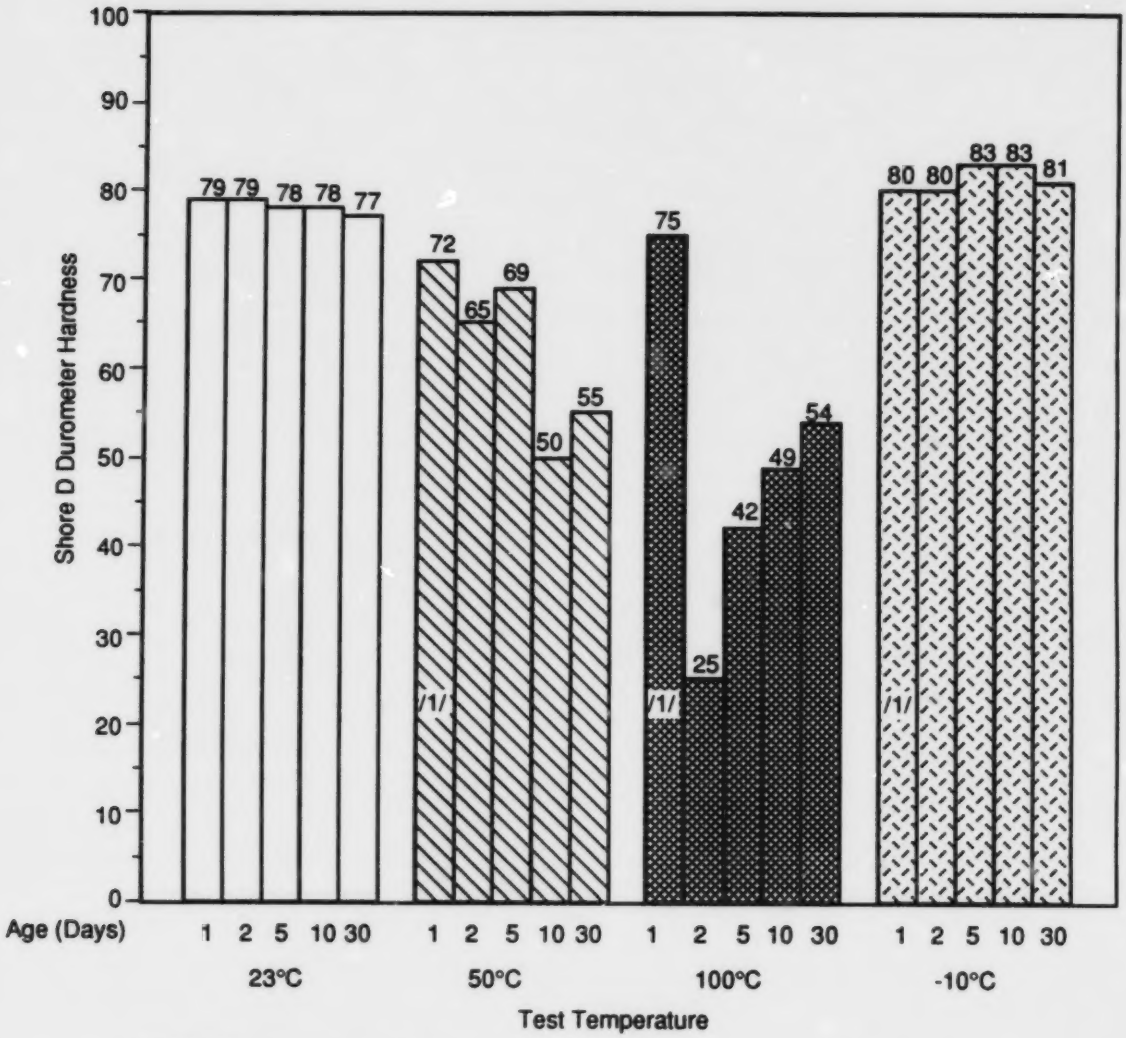
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS POLYCAST WTR



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A12

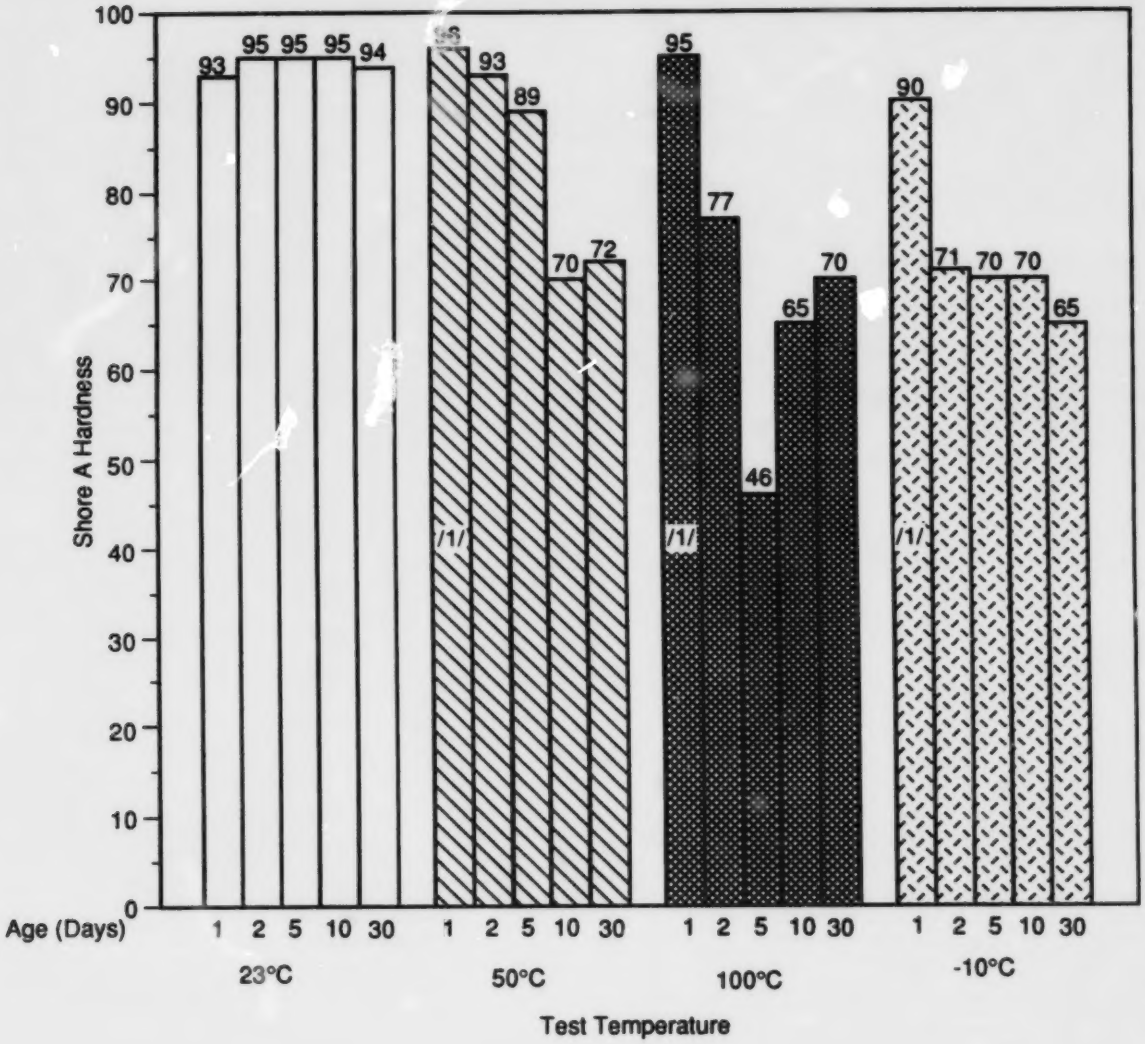
EFFECT OF EXPOSURE TEMPERATURE ON SHORT A DUROMETER HARDNESS LV4



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A13

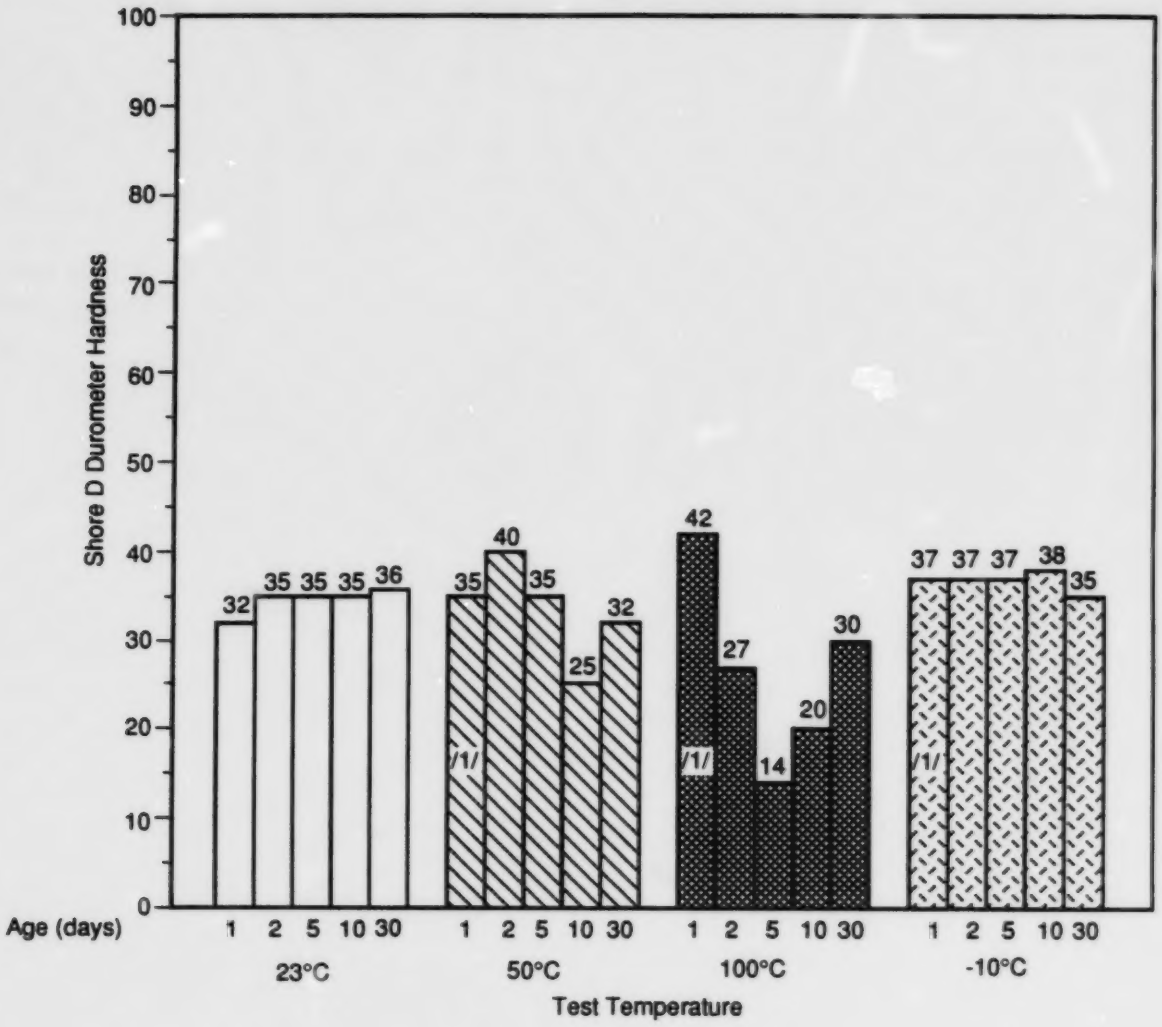
EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS LV4



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A14

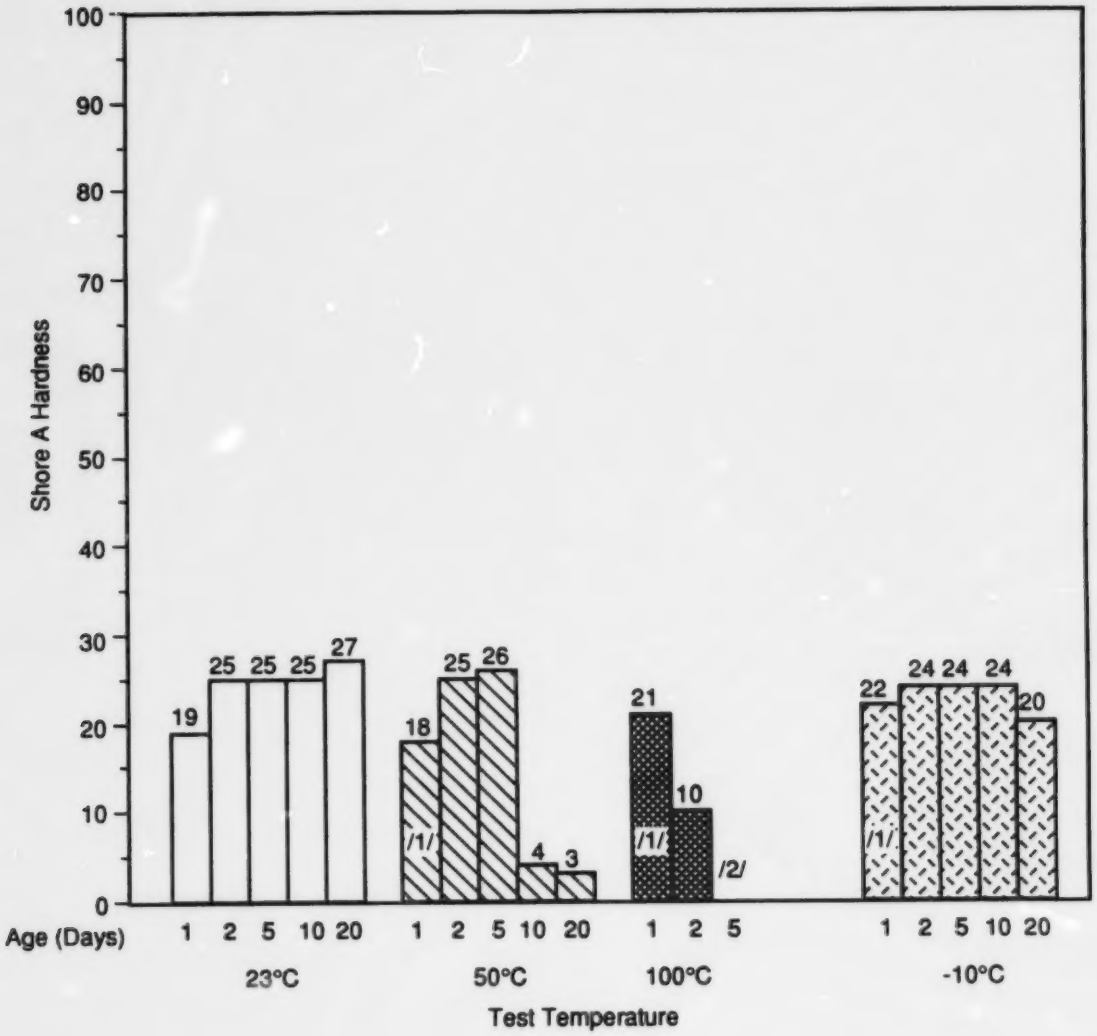
EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS LV3



/1/ Initial 24 hour measurement taken at 23°C

FIGURE A15

EFFECT OF EXPOSURE TEMPERATURE ON SHORE D DUROMETER HARDNESS LV3



/1/ Initial 24 hour measurement taken at 23°C

/2/ Material melted

FIGURE A16

EFFECT OF EXPOSURE TEMPERATURE ON SHORE A DUROMETER HARDNESS ELMF

APPENDIX B

Epoxy and Polyurethane Injection of Plexiglas/Concrete Models

Figure	B-1	Epoxy injection of simulated cracks	Capweld F2
	B-2	Epoxy injection of simulated cracks	Capweld F3
	B-3	Epoxy injection of simulated cracks	Capweld F3
	B-4	Epoxy injection of simulated cracks	8132
	B-5	Epoxy injection of simulated cracks	8132
	B-6	Polyurethane injection of simulated cracks	Polycast WTR
	B-7	Polyurethane injection of simulated cracks	LV3
	B-8	Polyurethane injection of simulated cracks	ELMF

Table	B-1	Epoxy injection of simulated cracks	Capweld F2
	B-2	Epoxy injection of simulated cracks	Capweld F3
	B-3	Epoxy injection of simulated cracks	Capweld F3
	B-4	Epoxy injection of simulated cracks	8132
	B-5	Epoxy injection of simulated cracks	8132
	B-6	Polyurethane injection of simulated cracks	Polycast WTR
	B-7	Polyurethane injection of simulated cracks	LV3
	B-8	Polyurethane injection of simulated cracks	LV3
	B-9	Polyurethane injection of simulated cracks	ELMF

NOTES:

(1) Where polyurethane injection machine was used, the injection pressure was less than 20 psi.

(2) Where a hand operated caulking gun was used, injection pressures ranged from approximately less than 20 to 160 psi.

(3) The attached drawings show the flow patterns for the materials injected into the plexiglas/concrete models.

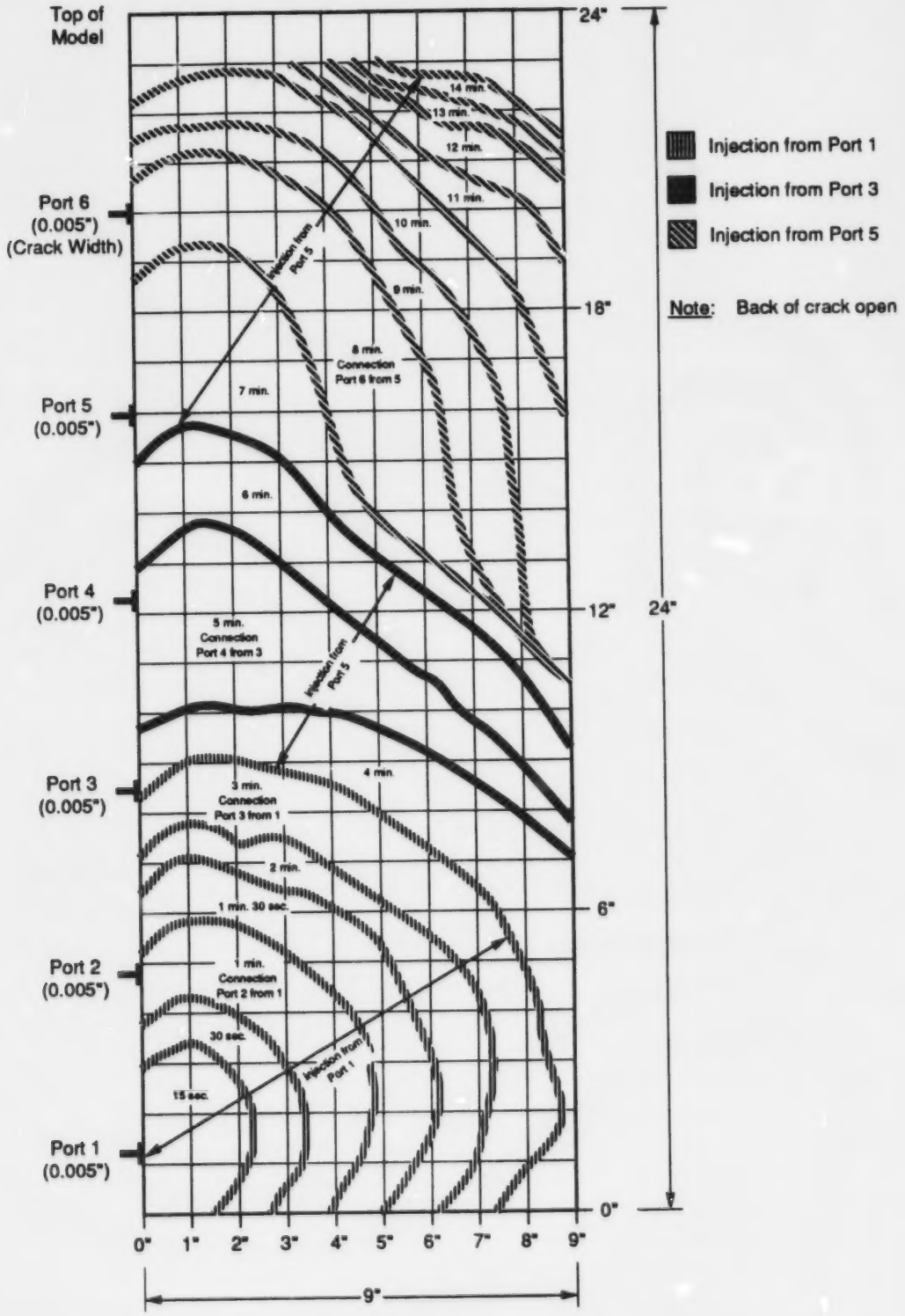


FIGURE B-1

FLOW PATTERN OF EPOXY INJECTION RESIN F2 - 8000 cps
PLEXIGLAS/CONCRETE MODEL

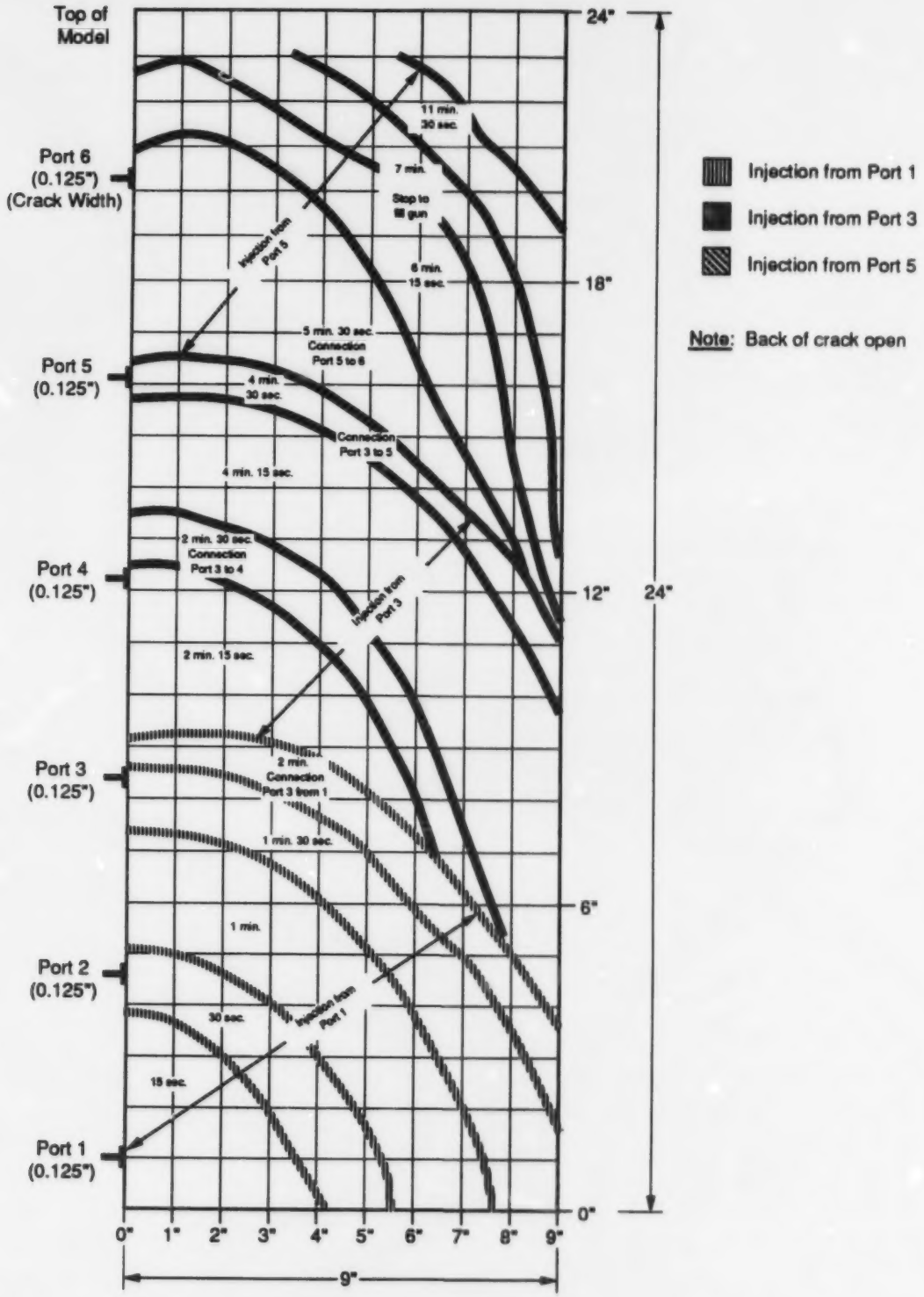


FIGURE B-2

FLOW PATTERN OF EPOXY INJECTION RESIN F3 - 16,000 cps PLEXIGLAS/CONCRETE MODEL

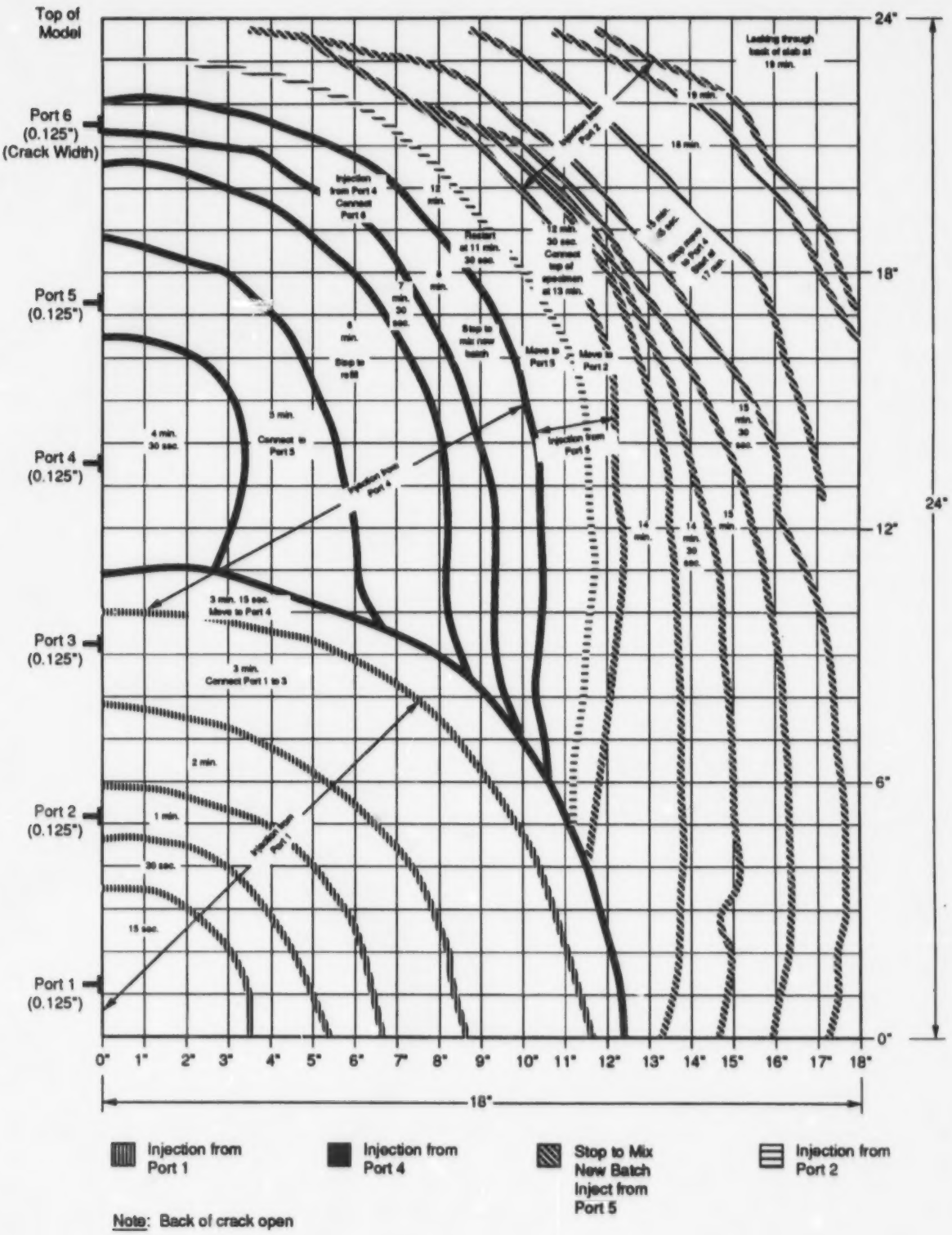


FIGURE B-3

FLOW PATTERN OF EPOXY INJECTION RESIN F3 - 16,000 cps
PLEXIGLASS/CONCRETE MODEL

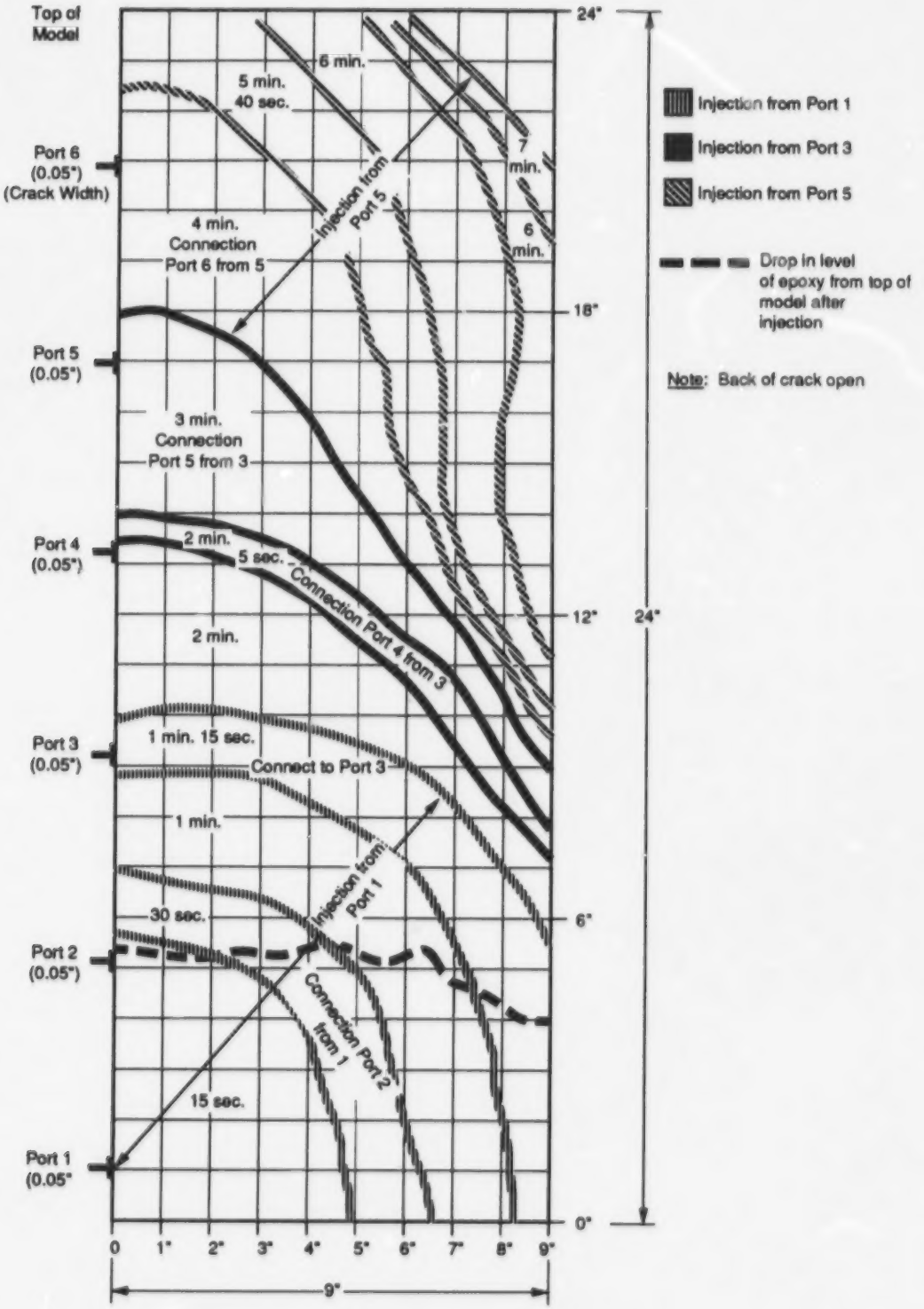
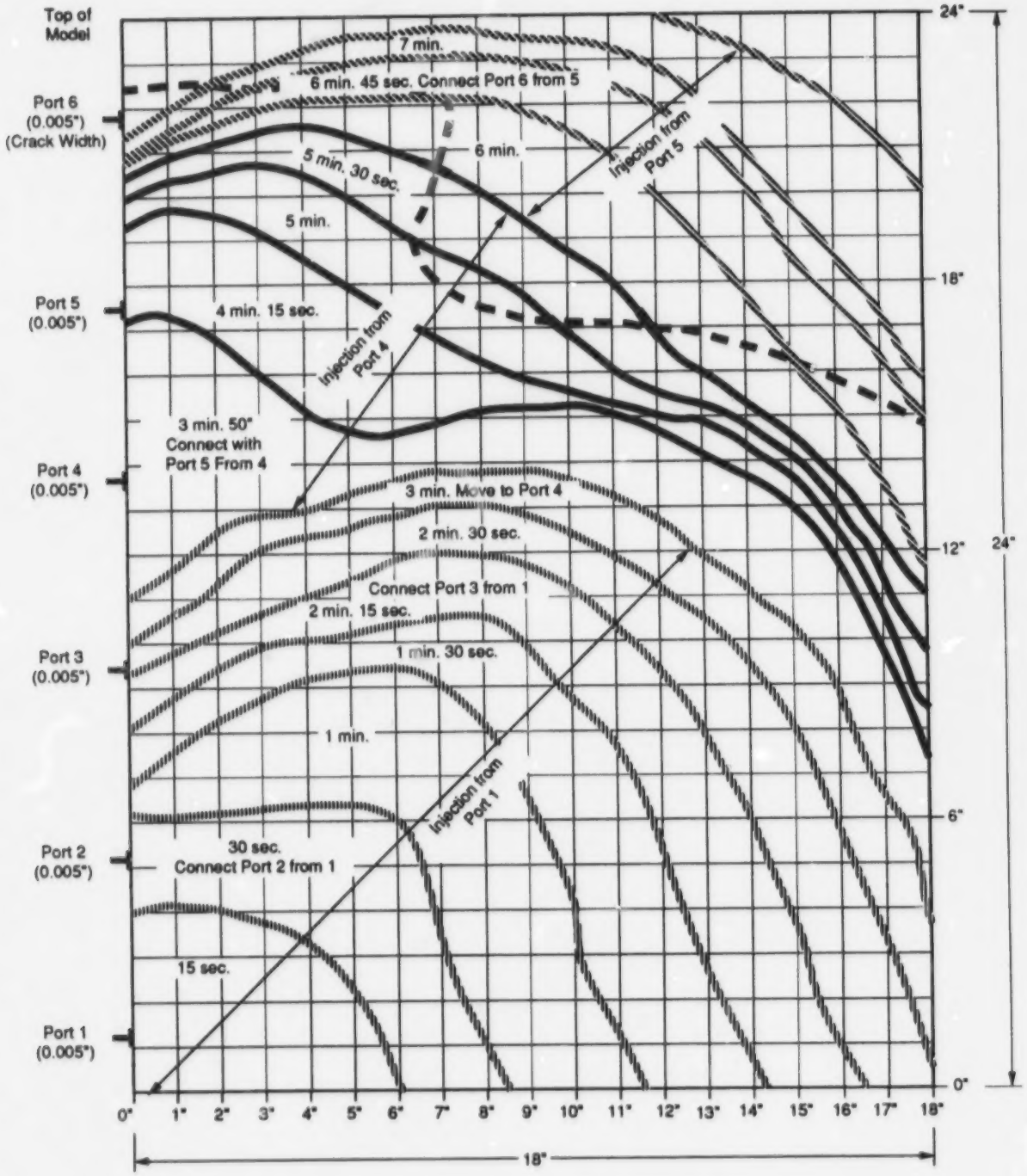


FIGURE B-4

FLOW PATTERN OF EPOXY INJECTION RESIN 8132-2000 cps PLEXIGLAS/CONCRETE MODEL


Top of Model
Port 6 (0.005") (Crack Width)
Port 5 (0.005")
Port 4 (0.005")
Port 3 (0.005")
Port 2 (0.005")
Port 1 (0.005")
7 min.
6 min. 45 sec. Connect Port 6 from 5
6 min.
5 min. 30 sec.
5 min.
4 min. 15 sec.
3 min. 50" Connect with Port 5 From 4
3 min. Move to Port 4
2 min. 30 sec.
Connect Port 3 from 1
2 min. 15 sec.
1 min. 30 sec.
1 min.
30 sec. Connect Port 2 from 1
15 sec.
Injection from Port 5
Injection from Port 4
Injection from Port 1
24"
18"
12"
6"
0"
0" 1" 2" 3" 4" 5" 6" 7" 8" 9" 10" 11" 12" 13" 14" 15" 16" 17" 18"
18"
Injection from Port 1
Injection from Port 4
Injection from Port 5
Drop in level of epoxy from top of crack after injection

Note: Back of crack open

FIGURE B-5

FLOW PATTERN OF EPOXY INJECTION RESIN 8132-2000 cps PLEXIGLASS/CONCRETE MODEL

182459-A22-RD

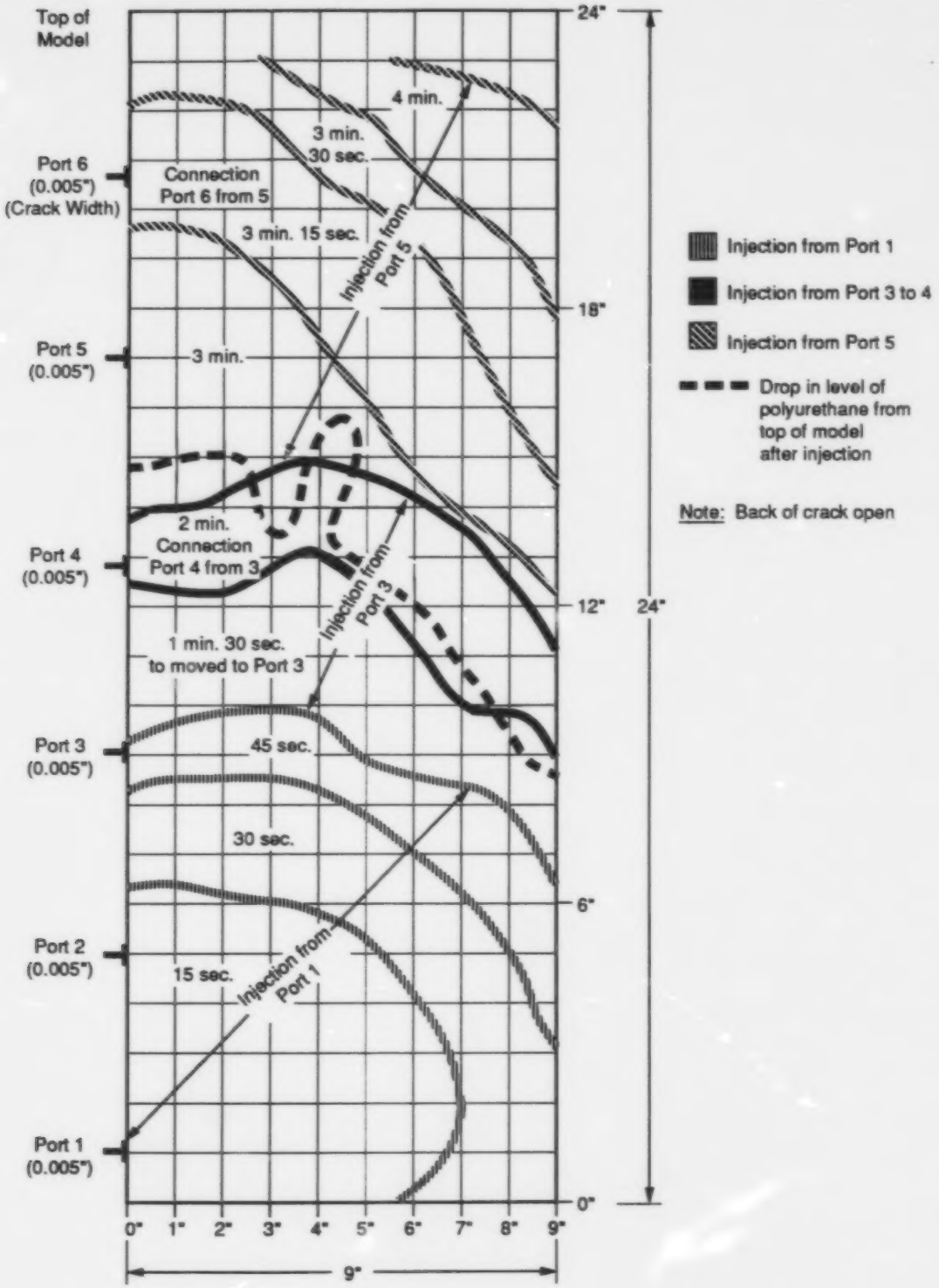


FIGURE B-6

FLOW PATTERN OF POLYURETHANE INJECTION RESIN POLYCAST WTR - 200 cps PLEXIGLAS/CONCRETE MODEL

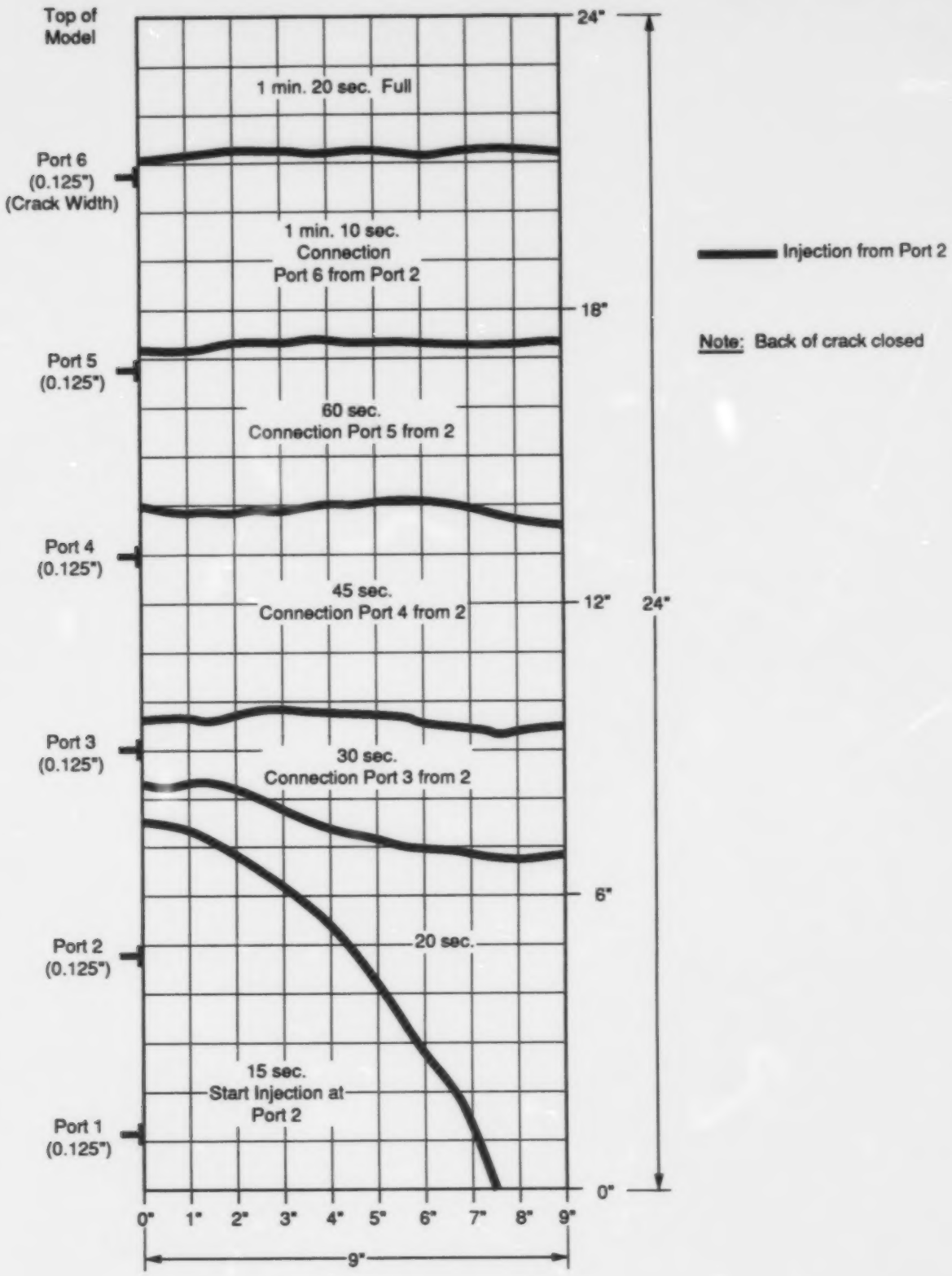


FIGURE B-7

FLOW PATTERN OF POLYURETHANE INJECTION RESIN LV3 - 200 cps PLEXIGLAS/CONCRETE MODEL

182488-A23-RD

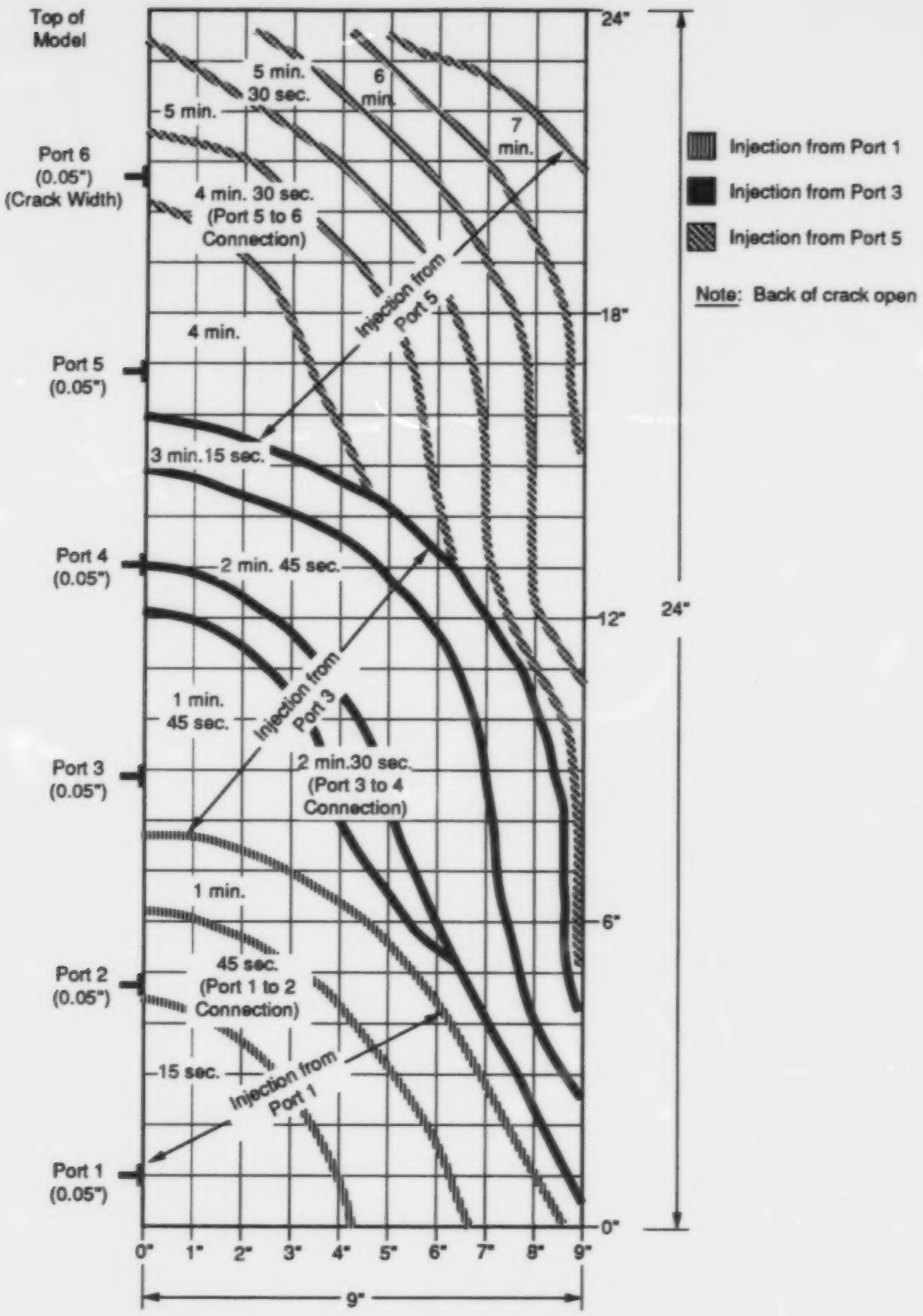


FIGURE B-8

FLOW PATTERN OF POLYURETHANE INJECTION RESIN ELMF-2800 cps PLEXIGLAS/CONCRETE MODEL

TABLE B1

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 23/90
Material: Capweld F2
Viscosity: 8 000 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.005"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORT	REMARKS
0'0"	1	140	-	-	
1'30"	1	140	-	2	
2'	1	-	-	-	
3'	1	-	-	-	Leaking out back of crack
3'30"	1	140	-	3	
4'	3	120	2.0	-	
5'	3	-	-	4	
6'	3	120	4.0	-	
6'30"	5	130	-	-	
8'	5	-	-	6	
9'	5	-	-	-	Connect top of specimen
10'	5	140	5.0	-	
12'	5	-	-	-	
13'	5	-	-	-	
14'	5	140	-	-	Approximately 2 fl. oz leaked out back of crack. No reduction in level of grout in crack.
15'	5	-	8.0	-	

Note: Measured epoxy thickness in crack after allowing material to cure: 0.005" to 0.01".

TABLE B2

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: Capweld F3
Viscosity: 16 000 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.125"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORT	REMARKS
0'0"	1	20	-	-	Material easy to inject.
0'15"	1	20	-	-	
30"	1	20	-	2	
1'	1	20	2.0	-	
1'30"	1	20	-	-	
2'	1	20	-	3	Very small quantity of epoxy leaked out back of crack.
2'15"	3	30	-	-	
2'30"	3	30	-	4	
4'15"	3	30	8.0	-	
4'30"	3	30	-	5	
5'30"	5	30	-	6	
6'15"	5	30	-	-	
7'	5	-	14.0	-	
11'	5	-	-	-	
11'30"	5	30	-	-	
12'	5	-	23.0	-	2 fl. oz. leaked out of crack.

Note: Measured epoxy thickness in crack after allowing material to cure: 0.120" to 0.140".

TABLE B3

EPOXY INJECTION OF SIMULATED CRACK

Date: Jan 30/90
Material: Capweld F3
Visxosity: 16 000 cps

Model: Plexiglas/Concrete-18" wide (Back of crack open)
Crack Width: 0.125"
Injection Equipment: Caulking Gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORTS	REMARKS
0'0"	1	-	-	-	Material easy to inject. Required relatively high injection pressure to fill void.
15"	1	90	-	-	
30"	1	-	-	-	
1'	1	120	3.0	2	
2'	1	-	-	-	
3'	1	-	9.0	3	
3'15"	4	-	-	-	
4'30"	4	-	-	-	
5'	4	-	12.0	5	
6'	4	-	-	-	
7'30"	4	-	-	-	
8'	4	-	17.0	6	
11'30"	-	-	-	-	Mixed new batch of material.
12'	5	145	-	-	
12'30"	5	-	-	Top of specimen	
13'	2	-	27.0	-	Moved to port 2 to fill back of crack.
14'	2	-	-	-	
14'30"	2	-	-	-	
15'	2	-	34.0	-	
15'30"	2	-	-	-	
15'45"	2	-	45.0	-	5.0 fl. oz. leaked out back of crack during injection. 1 to 2 fl. oz. leaked out after injection.
18'	2	-	-	-	
19'	2	-	-	-	

Note: Measured epoxy thickness in crack after allowing material to cure: 0.125" to 0.150".

TABLE B4

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: 8132
Viscosity: 2 000 cps

Model: Plexiglas/Concrete-18"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORT	REMARKS
0'0"	1	-		-	Material required relatively high injection pressures to penetrate crack. Crack filled easily.
0'15"	1	140		-	
30"	1	-		2	
1'	1				
1'30"	1	-		-	
2'15"	1	-		3	
2'30"	1	-		-	
3'	4	-		-	
3'30"	4	150		5	
4'15"	4	-		-	
5'	4	-		-	
5'30"	4	150		-	
6'	5	-		-	
6'45"	5	-		6	
7'	5	-	13.0	-	4.0 fl. oz. of epoxy leaked out through back of crack. Level of epoxy in crack reduced by 25% after injection.

Note: Measured epoxy thickness in crack after allowing material to cure: 0.005" to 0.01".

TABLE B5

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 2/90
Material: 8132
Viscosity: 2 000 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	20			
0'15"	1	20			
30"	1	20			Material leaking through back of crack.
1'	1	20			
1'15"	1	20		3	
2'	3	20			
2'15"	3	20		4	
3'	3	20	7.0	5	
4'	5	-		6	
5'30"	5	-			
6'	5	20			
6'30"	5	-			
7	5	20	15.0		4 fl. oz. leaked out back of crack. 80% of mat'l leaked out of crack at end of injection.

Note: Measured epoxy thickness in crack after allowing material to cure: 0.05" to 0.065".

TABLE B6

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 25/90
Material: Polycast WTR
Viscosity: 200 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	30	-	-	
15"	1	30	-	2	Polyurethane flowed easily into crack. Polyurethane leaking through back of crack at base.
45"	1	30	-	-	
1'30"	3	40	2.0	-	-
1'45"	3	40	-	4	Material leaking through back of crack.
2'45"	3	40	-	-	-
3'	5	40	4.0	-	-
3'15"	5	40	-	6	-
4'	5	40	6.0	-	Injection complete. 2.7 fl. oz. of epoxy leaked through back of crack. Approximately 45% of crack empty.
11"	-	-	-	-	-

Note: Measured polyurethane thickness in crack after allowing material to cure: 0.005" to 0.009".

TABLE B7

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: LV3
Viscosity: 70 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.125"
Injection Equipment: Polyurethane Injection Machine

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	2	<20	-	-	Material easy to inject.
15"	2	<20	3.0	-	
20"	2	<20	4.0	-	
30"	2	<20	6.0	3	
45"	2	<20	9.0	4	
60"	2	<20	5	-	
1'10"	2	<20	14.0	6	
1'20"	2	<20	16.0	Top of Model	Material started to expand approximately 7 min after injection.

Note: Measured polyurethane thickness in crack after allowing material to cure: 0.125" to 0.140".

TABLE B8

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 26/90
Material: LV3
Viscosity: 70 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	20			
0'15"					
20"					Material immediately started to leak out back of crack.
1'					
2'				2	
3'		20	16.0		16.0 fl. oz. leaked out of crack at end of injection.

TABLE B9

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 25/90
Material: ELMF
Viscosity: 2 800 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	20	-	-	Polyurethane flowed easily into crack.
45"	1	20	-	2	
1'15"	3	20	3.0	-	Polyurethane leaking through back of crack.
1'45"	3	30	-	-	
2'30"	3	30	6.0	4	
2'45"	3	60	-	-	
3'15"	5	-	8.0	-	
4'0"	5	40	-	-	
4'30"	5	-	11.0	6	
5'0"	5	60	-	-	
5'30"	5	-	15.0	-	
6'0"	5	80	-	-	
7'0"	5	80	18.0	-	Injection complete. Approximately 1-2 fl. oz. leaked out back of crack.

Note: Measured polyurethane thickness in crack after allowing material to cure: 0.05" to 0.07".

APPENDIX C

Epoxy and Polyurethane Injection of Concrete/Concrete Models

Table	C-1	Epoxy injection of simulated cracks	Capweld F1
	C-2	Epoxy injection of simulated cracks	Capweld F3
	C-3	Epoxy injection of simulated cracks	Capweld 333
	C-4	Epoxy injection of simulated cracks	8132
	C-5	Epoxy injection of simulated cracks	8132
	C-6	Polyurethane injection of simulated cracks	Polycast WTR
	C-7	Polyurethane injection of simulated cracks	Polycast WTR
	C-8	Polyurethane injection of simulated cracks	LV4
	C-9	Polyurethane injection of simulated cracks	LV3
	C-10	Polyurethane injection of simulated cracks	LV3
	C-11	Polyurethane injection of simulated cracks	ELMF
	C-12	Polyurethane injection of simulated cracks	ELMF

NOTES:

(1) Where polyurethane injection machine was used, the injection pressure was less than 20 psi.

(2) Where a hand operated caulking gun was used, injection pressure ranged from 20 to 200 psi.

(3) The attached tables identify the injection process, injection pressures, quantity of material injected and any remarks made during injection.

TABLE C1

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: Capweld F1
Viscosity: 2 300 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: ≈.005"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORT	REMARKS
0'0"	1	30	-	-	Material easy to inject.
45"	1	40	-	2	
1'	1	40	3	-	
1'45"	1	40	-	3	Material leaked out back of crack.
2'45"	4	140	9	-	
3'15"	4	160	-	5	
4'25"	4	160	-	6-	
5'	4	160	15	Top of model	
5'30"	4	160	-		
6'	4	160	18	-	Stop Injection. Material continued to leak out back of crack after injection. 8 fl. oz. of epoxy leaked out.

TABLE C2

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: Capweld F3
Viscosity: 16 000 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.125"
Injection Equipment: Polyurethane Injection Machine

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORT	REMARKS
0'0"	1	100	-	-	
45"	1	100	-	2	
1'45"	1	120	-	3	
4'	1	-	16	4	
5'	1	-	20	-	Material starting to come out back of crack.
5'30"	4	120	-	-	
6'	4	-	24	5	
7'45"	4	-	-	6	
8'45"	4	120	-	Top of model	
9'	3	-	36	-	
11'	3	-	44	-	Material coming out along 9" top, 14" side of crack.
13'	3	120	52	-	
15'30"	3	-	-	-	
17'30"	3	120	65	-	Material coming out 15" top, 20" side of crack. Approx 16 fl. oz. leaked out along to top and back of crack during injection. No further leakage after stoppage injection.

TABLE C3

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: Capweld 333
Viscosity: 9 200 cps

Model: Plexiglas/Concrete-9"Width
(Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORT	REMARKS
0'	1	20	-	-	Material very easy to inject into crack.
35"	1	-	-	2	
1'20"	1	-	10	3	
1'50"	1	30	-	4	
2'30"	1	-	-	5	
30'	1	30	15	6	
3'50"	1	-	-	Coming out of top	
4'15"	1	-	23	-	Stop

TABLE C4

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 31/90
Material: 8132
Viscosity: 2 000 cps

Model: Concrete/Concrete - 9" wide
(Back of crack closed)
Crack Width: 0.05
Injection Equipment: Hypodermic needle

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORTS	REMARKS
0'0"	2	-	-	-	Material easy to inject.
1'30"	2	-	4.0	3	
2'40"	2	-	6.0	4	
4'15"	2	-	8.0	5	
5'50"	2	-	10.0	6	
6'15"	2	-	11.0	Top of model	Model full.

TABLE C5

EPOXY INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: 8132
Viscosity: 2 000 cps

Model: Concrete/Concrete - 9" width
(Back of crack closed)
Crack Width: 0.05
Injection Equipment: Caulking Gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF EPOXY INJECTED (fl. oz.)	EPOXY CONNECTION WITH PORTS	REMARKS
0'	1	-	-	-	
45"	1	100	-	2	Material leaking out back of crack.
1'15"	3	120	-	-	
1'45"	4	140	-	-	
2'30"	4	140	8	5	Significant amount of material leaked out back of crack during injection.
3'30"	5	140	-	-	
3'45"	5	140	-	-	
4'0"	6	140	-	Top of crack	
5'0"	6	140	16		Material continued to leak out back of crack after injection. 8 fl. oz. of material leaked out of crack during and after injection.

TABLE C6

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 31/90
Material: Polycast WTR
Viscosity: 200 cps

Model: Concrete/Concrete - 9" Width (Back of crack sealed)
Crack Width: 0.005"
Injection Equipment: Hypodermic needle

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl oz)	POLYURETHANE CONNECTION WITH PORTS	REMARKS
0'0"	1	-	-	-	Material easy to inject.
1'30"	1	-	2.0	2	
2'	1	-	-	3	
2'10"	1	-	4.0	4	
3'15"	1	-	-	5	
3'40"	1	-	6.0	6	
5'	1	-	8.0	Top of model	Specimen full.

TABLE C7

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: Polycast WTR
Viscosity: 200 cps

Model: Plexiglas/Concrete-18"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'	1	30	-	-	Material very easy to inject.
30"	1	-	-	2	
1'30"	1	60	5.0	3	
2'45"	1	60	-	4	
3'40"	1	-	11.0	5	
4'25"	1	60	-	6	
5'	1	-	-	Connect with top of crack	
5'40"	1	-	19	-	Stop.

TABLE C8

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: LV4
Viscosity: 70 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Polyurethane Injection Machine

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	<20	-	-	Material easy to inject.
15"	1	<20	3.0	2	
30"	1	<20	6.0		
35"	1	<20	-	3	
40"	1	<20	8.0	4	
45"	1	<20	9.0	5	
50"	1	<20	11.5	6	No expansion of material.

TABLE C9

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: LV3
Viscosity: 70 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Polyurethane Injection Machine

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	<20	-	-	Material easy to inject.
20"	1	-	-	2	
45"	1	-	9	3	Small quantity of polyurethane leaking through back of crack.
1'20"	1	300	-	4	
1'30"	1	500	18	4	Line on machine blew.
1'40"	4	<20	-	5	
1'50"	4	-	-	6	
2'30"	4	<20	30	Top of model	Specimen full. Material started to expand within 15 min of injection. Approximately 1 to 3 fl. oz. leaked out during injection.

TABLE C10

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: LV3
Viscosity: 70 cps

Model: Plexiglas/Concrete-18"Width (Back of crack open)
Crack Width: 0.125"
Injection Equipment: Polyurethane Injection Machine

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'0"	1	<20	-	-	Material easy to inject.
0'15"	-	<20	3.0	-	
0'30"	1	<20	6.5	2	
1'0"	1	<20	13.5	3	
1'15"	1	<20	20.5	4	
1'30"	1	<20	27.5	5	
2'0"	1	<20	41.5	6	
2'30"	1	<20	55.0	Top of model	Material leaked through base of model. Specimen refilled with polyurethane. Material expanded within 10 min of injection.

TABLE C11

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: ELMF
Viscosity: 2 800 cps

Model: Plexiglas/Concrete-18"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking Gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'	1	-	-	-	
45"	1	120	-	2	
1'30"	1	140	5.0	3	
2'50"	1	140	-	4	Leaking out back of crack during injection.
4'	3	160	12.0	-	
5'	3	160	-	5	
5'	4	-	15.0	-	
6'40"	4	160	-	6	
7'30"	4	-		Coming out top of model	
9'	-	-	26.0	-	Material leaked out slowly from back of crack after injection. 6 fl. oz. of material leaked out top and back of crack during injection.

TABLE C12

POLYURETHANE INJECTION OF SIMULATED CRACKS

Date: Jan 30/90
Material: ELMF
Viscosity: 2 800 cps

Model: Plexiglas/Concrete-9"Width (Back of crack open)
Crack Width: 0.05"
Injection Equipment: Caulking Gun

TIME	INJECTION FROM PORT	INJECTION PRESSURE (psi)	CUMULATIVE QUANTITY OF POLYURETHANE INJECTED (fl. oz.)	POLYURETHANE CONNECTION WITH PORT	REMARKS
0'	1	140	-	-	
45"	1	-	-	2	
1'15"	1	-	-	-	Leaking out back of crack.
1'45"	3	180	-	-	Port very tight.
2'20"	4	200	-	-	Port very tight.
2'45"	1	150	-	-	Very difficult to inject model.
4'15"	5	200	11.0	-	Material started to thicken. Test completed - 1/2 of model filled.
6'40"	4	160	-	6	
7'30"	4	-		Coming out top of model	
9'	-	-	26.0	-	Material leaked out slowly from back of crack after injection. 6 fl. oz. of material leaked out top and back of crack during injection.